Notes on Heating and Ventilation

NOTES

ON

HEATING and VENTILATION

BY

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Member American Society Heating and
Ventilating Engineers

Member American Society Mechanical
Engineers

Member American Society Promotion
Engineering Education

THIRD EDITION

DOMESTIC ENGINEERING COMPANY
CHICAGO
443 So. Dearborn Street
1911

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PREFACE

THE subject matter originally contained in this book was a reprint from a series of articles published in Domestic Engineering. In this edition the original text has been rewritten and a large amount of additional information included.

This book was written primarily to show that the subject of Heating and Ventilation could be developed in a logical way from the fundamental principles of engineering. The great lack has been in the amount of scientific information available regarding the actual laws of heat and the value of the constants entering into these laws. The University of Michigan has carried on, under the direction of M. E. Cooley, Dean of the Engineering Department, a series of experiments for over twenty years. The results of these experiments are given in various tables and serve to give the designer data from actual experiments upon which he can base his calculations.

There has been included in this edition a resume of the results of the German experiments and these methods of determining heat losses from buildings. This matter is largely reprints from a book published by the "Metal Worker" under the title, "Formulae and Tables for Heating" by J. H. Kinealy. This book has been written primarily for the steamfitter and designer of heating systems. It presupposes some elementary knowledge of the details of construction and operation of the simpler forms of heating plants.

The author has used the previous editions as a text for his classes in Heating and Ventilation. The present edition has been written with a view to making the book more desirable as a college text.

July 1, 1911. John R. Allen.

INTRODUCTION

Heat.—Heat is a form of motion. In modern science, all matter is conceived as being made up of small particles called molecules. These particles do not exist in a state of rest, but are in constant vibration. If these particles move slowly the body is at a low temperature; if they move more rapidly the body is at a higher temperature, the temperature of the body being determined by the rapidity of the motion of the particles. In measuring heat there are two properties to be considered—the intensity and the quantity. This may be compared to measuring water in a pipe. We measure the pressure of the water in the pipe by means of a gauge in pounds per square inch. The quantity of water is measured in pounds. In the same way the intensity of heat is measured by the thermometer in degrees and the quantity of heat is measured by comparison with the quantity of heat which a pound of water will absorb.

Temperature.—Temperature, which is a measure of the intensity of the heat of a body, might also be considered as measuring the velocity of the molecules of the body. In mechanical engineering all measurements of temperature are made on the Fahrenheit scale. On this scale the freezing point is taken at 32° and the boiling point as 212°, the tube of the thermometer between these points being divided into 180 equal parts called degrees.

We never know the total amount of heat in a body.

As it is impossible to bring any body to a condition of absolutely no heat, the heat in any body must always be measured from some assumed zero point and in the Fahrenheit scale this assumed zero point is 32° below the freezing point. For theoretical purposes, however, it is highly desirable to have some absolute standard of heat. A perfect gas at 32° contracts about 1/493 of its volume for each degree Fahrenheit that it is reduced in temperature. If, then, we keep on decreasing the temperature of a perfect gas from 32°, until it reaches a point 493° below 32° Fahrenheit, it would have, theoretically, no volume. If it has no volume, the amount of heat which it contains must be zero. This point, then, is called the absolute zero. This point is manifestly an ideal one. To find the absolute temperature in degrees it is necessary to add to the Fahrenheit temperature 461 degrees, that is, 32° Fahrenheit corresponds to 493° absolute.

Unit of Heat.—Heat is not a substance and it can not be measured as we would measure water in pounds or cubic feet, but it must be measured by the effect which it produces. Suppose it requires a certain amount of heat to raise a pound of water from 39° to 40° Fahrenheit. It would require three times that quantity of heat to raise a pound of water from 39° to 42° Fahrenheit. The heat required to raise a pound of water one degree Fahrenheit is called a British thermal unit, and is designated by letters B. t. u.

Relation Between Heat and Work.—Work is measured in foot-pounds. The unit of work is the work required to raise one pound through a height of one foot. Ten units of work or ten foot-pounds would be the amount of work done in raising ten pounds one foot high or one pound ten feet high. Heat is a form of motion, hence there must be some definite relation be-

tween heat and work. This relation was first determined by Joule. By a series of experiments Joule found that one heat unit was equivalent to 778 foot-pounds. It is possible, then, to express heat either in heat units or in foot-pounds.

Specific Heat.—Different substances require very different quantities of heat to produce the same change of temperature for the same weight. As for example, to raise one pound of water one degree requires one B. t. u.; to raise one pound of ice one degree requires .504 B. t. u.; to raise one pound of wrought iron one degree requires .1138 B. t. u. The heat necessary to raise one pound of a substance one degree, expressed in British thermal units, is called specific heat. The following table gives the specific heat of the principal substances which we meet with in engineering work:

TABLE I. SPECIFIC HEATS.

Substance.	B. t. u.
Liquids.	
Water	1.000
Alcohol	.622
Turpentine	.472
Petroleum	.434
Olive Oil	.309
Metals.	
Cast iron	.1298
Wrought iron	.1138
Soft steel	.1165
Copper	.0951
Brass	.0939
Tin	.0569
Lead	.0314
Aluminum	.2185
Minerals.	
Coal	.2777
Marble	.2159
Chalk	.2149
Stones generally	.2100
Limestone	.2170
Building Materials.	
Brick work	.1950
Masonry	.2159
Plaster	.2000
Pine wood	.467
Oak wood	.570
Birch	.480
Glass	.1977

Example.—It is required to raise the temperature of a cast iron radiator weighing 300 pounds from 70° to 212°. The temperature through which the iron would be raised would then be 212 minus 70° or 142°. From the table we see that it would require to raise one pound of cast iron one degree .1298 heat units, then to raise one pound 142° would require 142 times .1298 or 18.43 heat units, and to raise 300 pounds one degree would require 300 times this amount or 5,529 B. t. u., the heat required to heat the radiator. This is important in heating as the walls of a cold building must be heated.

Example.—A church 80′x100′ with walls 2½ feet thick for 10 feet above the ground and for the remaining 20 feet 2 feet thick. The roof has a ½ pitch and is made of 2″x8″ rafters, 16 inches on centers, covered with 1 inch of pine boarding, tar paper and slate ¼ inch thick. Main floor composed of two 1-inch thicknesses of boards laid on 2″x12″ joists, 16-inch centers. Ceiling is of plaster ¾ in thick. The church has 20 windows, 6 feet wide and 15 feet high, 12 windows, 4 feet wide and 6 feet high, and 2 doors, 8 feet wide and 12 feet high. Allowing an addition of 15% of furnishings, find the heat required to raise the temperature of the church from 0° to 50°.

Weight of stonework, stone weighing 160 pounds per cubic foot.

$$370 \times 10 \times 2\tfrac{1}{2} \times 160 = 1{,}480{,}000 \text{ pounds}$$
$$368 \times 20 \times 2 \times 160 = 2{,}350{,}000 \text{ "}$$
$$\frac{80}{2} \times 40 \times 2 \times 2 \times 160 = 1{,}024{,}000 \text{ "}$$

Total weight of masonry assuming building to be without openings } 4,854,000 "

Weight of wood work. Weight per cubic foot taken as 40 pounds.

$\frac{2\times8}{144}\times56.2\times75\times2\times40. = 37{,}600$ pounds of rafters.

$56.2\times104\times2\times1/12\times40 = 39{,}000$ pounds of roof boards.

$80\times100\times2\times2/12\times40 = 107{,}000$ pounds of joists.

$\frac{2\times12}{144}\times80\times75\times2\times40\ldots = 80{,}000$ pounds of floor boards.

Total weight of wood-work...............263,600 pounds.

Slate—Weight per cubic foot taken as 170 pounds.

$56.5\times104\times2\times1/48\times170 = 41{,}600$ pounds.

Plaster—Weight per cubic foot taken as 90 pounds.

$(360\times30\times80\times40+100\times80)\ \tfrac{3}{4}\times1/12\times90 = 124{,}000$ pounds.

Air—Weight per cubic foot taken as .08 pounds.

$(80\times30\times100+\frac{80}{2}\times40\times100)\ .08 = 32{,}000$ pounds.

Heat required.

$4{,}854{,}000\times50\times.2159$	$= 52{,}300{,}000$	B. t. u.
$263{,}600\times50\times.65$	$= 8{,}580{,}000$	B. t. u.
$41{,}600\times50\times.2159$	$= 448{,}000$	B. t. u.
$124{,}000\times50\times.2$	$= 1{,}240{,}000$	B. t. u.
$32{,}000\times50\times.2375$	$= 379{,}000$	B. t. u.
	62,947,000	B. t. u.
Adding 15% for furnishing......	= 9,440,000	B. t. u.
Total to raise building and furnishing 50 degrees..........	=72,389,000	B. t. u.

This item is a large one in determining the size of the heating plant to be installed in a building intermittently heated.

In solid substances the change in volume when they are heated is so small that it is not considered. In gases, however, the change in volume when the gas is heated without being confined, depends directly upon the absolute temperature and may be very large. When air is confined and is heated, it cannot expand; if it does not expand there is no work done because, from our definition of work, it is necessary when work is done, that the body have some movement. On the other hand, when air receives heat and is free to expand it does work. For instance, if air were confined in a cylinder by a piston, and this air were heated, the air would expand and the piston would be moved out.

As the piston is moved through a certain space there must be work done. On the other hand, if the piston were blocked so that it could not move, then the air on being heated would do no work. Then in these two cases different amounts of heat will be required to raise the substance one degree, depending upon whether there is external work done or not. It is necessary then in gases that we consider two specific heats, the specific heat of constant volume and the specific heat of constant pressure. For air the specific heat of constant volume is .1689, for constant pressure it is .2375. It is seldom that we use air in a confined space, so that, so far as this work is concerned, we shall in most cases consider the specific heat of air as .2375—that is, to raise one pound of air one degree requires .2375 B. t. u., the pressure being constant.

TABLE IA. SPECIFIC HEATS OF GASES.

Substance.	Constant Pressure.	Constant Volume.
Air	.2375	.1689
Oxygen	.2175	.1550
Hydrogen	3.4090	2.4122
Nitrogen	.2438	.1727
Steam	.5000	.3500
Carbonic Acid Co_2	.2479	.1758
Ammonia	.508	.299

Notes on Heating and Ventilation

CHAPTER I

Heat Loss from Buildings.—Heat is lost from a room in three ways—by the direct transmission of the heat through the walls and windows; by the passage of air up the foul-air flues, and by the filtration of air through the walls and air leakage around doors and windows. The first two losses are easily determined, but the determination of the loss by filtration must always involve a large factor of judgment and experience.

All building construction is more or less porous. This is well exemplified by the old experiment made with a common brick. Two cornucopias of paper are pasted on opposite sides of a common brick, the large end of the cornucopias being fastened to the brick. Opposite the small end of the cornucopia at one side is placed a lighted candle. By blowing into the cornucopia on the opposite side, the candle may be blown out, the air having passed directly through the brick.

The experiments which have been made in order to determine the loss generally tend to show that in the ordinary well-constructed building the air in the room will change about once per hour, when all doors and windows are closed.

In order to study the other heat losses from a room it will be necessary to study the laws of cooling. A body may be cooled in three different ways—by radiation, by conduction and by convection (contact of

air). In order to understand these losses more thoroughly, each will be considered separately.

Radiation.—The heat that passes from a body by radiation may be considered similar to the light which is given off by a lamp. There is always a transfer of radiant heat from the body of a higher temperature to the body of lower temperature. The amount of heat

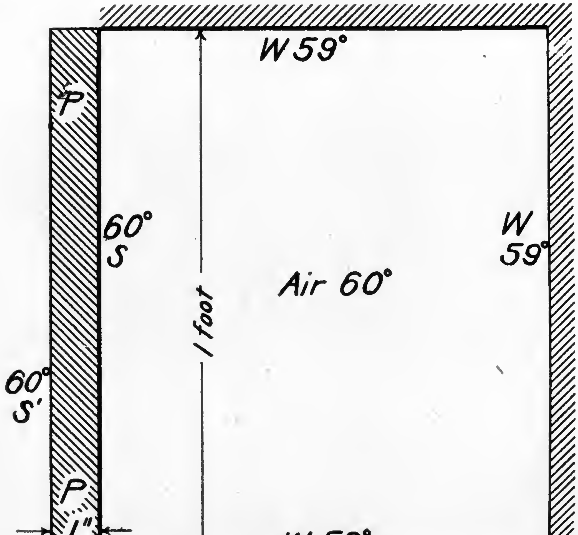


Fig. 1.

radiated will depend upon the difference in temperature between the bodies and the substance through which this heat passes and the material composing the surface from which the heat is radiated.

The losses by radiation may be better understood by referring to Fig. 1. Suppose the plate PP to be of

cast iron 1 foot square and 1 inch thick. Let us suppose this plate to be on both sides at a temperature of 60°. Let this plate form one side of a room, the walls WWW being non-conducting substances and at a temperature of 59°, the air in this space being at a temperature of 60°. Since the plate and the air in the space are at the same temperature, there will be no loss of heat from the air to the walls, but all the heat that passes from the plate PP to the walls must pass by radiation. For ordinary temperatures of heating surfaces, say 60 or 70°, the loss by radiation will equal the difference in temperature between the hot body and the cold body multiplied by a factor representing the radiating power of the body. The following table gives the radiating power of different substances:

TABLE II. RADIATING POWER.

Radiating power of bodies, expressed in heat units, given off per square foot per hour for a difference of one degree Fahrenheit. (Peclet.)

Copper, polished	.0327
Iron, sheet	.0920
Glass	.595
Cast iron, rusted	.648
Building stone, plaster, wood, brick	.7358
Woolen stuffs, any color	.7522
Water	1.085

Heat is radiated in straight lines exactly as light is given off from the source of light. We may have heat shadows the same as we have light shadows and the intensity of the heat is inversely proportional to the square of the distance from the source. Some bodies are transparent to heat and other bodies absorb heat, the same as some bodies are transparent to light and others absorb light. The transparency of bodies to heat is called diathermancy. Gases, such as air, oxygen, nitrogen, and hydrogen, are almost perfectly

transparent to heat, while wood, hair, felt and other non-conducting bodies are almost perfectly opaque to the transmission of heat. The loss of heat by radiation is independent of the form of a body so long as it does not radiate heat to itself. The color or condition of the surface of different bodies affects their radiant power. Smoothly polished surfaces radiate less heat than rough surfaces. As, for instance, a surface painted with lamp black will radiate over 13 times as much heat as a polished copper surface.

Example.—Suppose we have a glass surface five square feet in area. The glass surface is at a temperature of 70° and the objects surrounding it are at a temperature of zero. From the table we see that one square foot of glass (surface) loses .595 heat units in an hour for a difference of one degree between it and the surrounding objects. For a difference of 70°, then, each square foot of glass would lose 70 times that amount, or 41.5 heat units, and 5 square feet of glass would lose 5 times that amount, or 207.5 heat units per hour by radiation only.

Conduction.—The heat transmitted by conduction is the heat which is transmitted through the body itself.

TABLE III. CONDUCTING POWER.

The conducting power of materials, expressed in the quantity of heat units transmitted per square foot per hour by a plate one inch thick, the surfaces on the two sides of the plate differing in temperature by one degree. (Peclet.)

	B. t. u.
Copper	515
Iron	233
Lead	113
Stone	16.7
Glass	6.6
Brick work	5.6
Plaster	3.7
Pine wood	.76
Sheep's wool	.323

For example, take the condition shown in Fig. 2. PP is a plate, one side of which is enclosed by the walls WW. Let the temperature of the plate outside be 59°, the temperature on the inside of the plate be 60°; the temperature of the walls be 60°, and the temperature of the air in the room be 60°. Then all the heat that

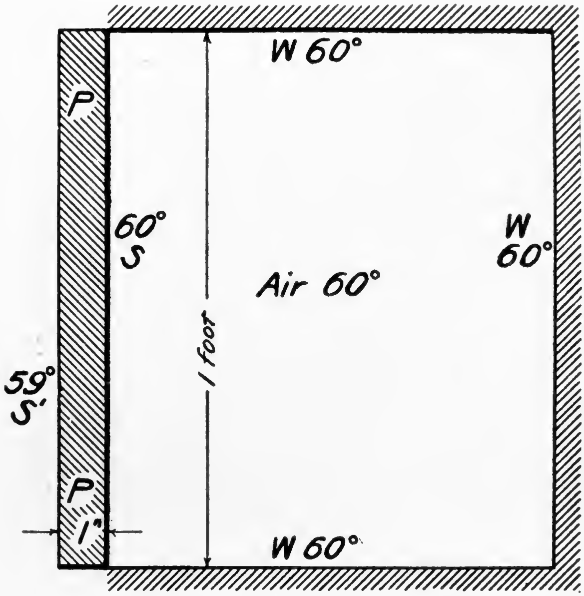


Fig. 2.

is lost by the room must be lost by direct conduction through the plate. PP. The amount of heat conducted will depend upon the material of which the conductor is composed and in addition it will also depend upon the difference in temperature between the two sides of the plate and upon the thickness of the plate. The

conduction through any plate may be calculated as follows:

Multiply the factor given in Table III by the difference in temperature between the two sides of the plate and divide the result by the thickness of the plate in inches. The quotient will be the heat transmitted by conduction per square foot of surface.

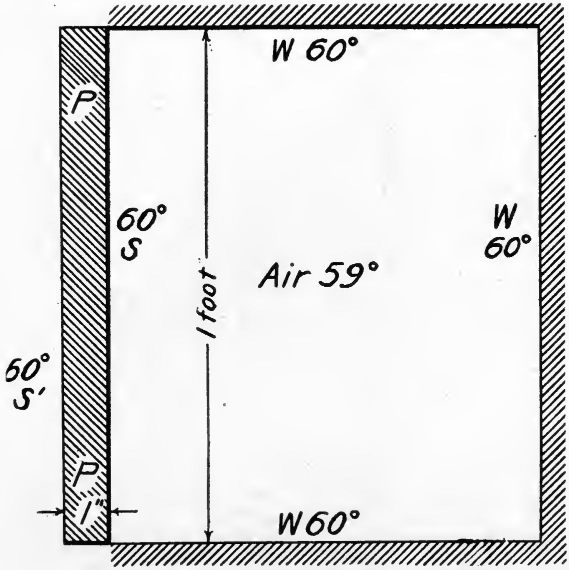


Fig. 3.

Example.—Suppose a boiler plate 5 feet square, ½-inch thick, to have a temperature of 70° on one side and a temperature on the opposite of 200°. The difference in temperature of the two sides of the plate would be 130°. The amount of heat conducted would then be $233 \times 130 \div \frac{1}{2} = 15{,}145$ B. t. u. per square

foot of plate per hour. Then five square feet would transmit five times this amount, or 75,725 B. t. u. in one hour.

Convection.—Loss by convection is sometimes termed loss by contact of air. Take, for example, the condition shown in Fig. 3. Let P be a vertical plane of metal one foot square, having its surfaces maintained at 60° temperature. Let the walls WW also be at a temperature of 60°. Let the air in the room be 59°. In this case there will be no loss of heat from the walls to the plate by radiation and there will be no loss through the plate by conduction, but heat will be transmitted from the walls and the plate to the air of the room. The air which comes in contact with the warmer walls will be heated. As air is heated it becomes lighter and rises and a current is formed. This produces a circulation of air, and this circulation of air gives rise to a loss of heat by convection or contact of air.

The loss of heat by convection is independent of the nature of the surface, wood, stone or iron losing the same quantity of heat, but it is affected by the form of the body—that is, a cylinder and a sphere would lose different amounts of heat per square foot. Take the steam radiator, for example. The air nearest the radiator becomes heated and rises; as it rises its place is taken by other colder air coming off the floor so that a current of air is established. In the ordinary type of radiator, the loss by contact of air represents about half the loss of heat, the balance being loss by radiation.

Calculation of Convection Losses.—The calculation of the heat lost by convection is quite complicated and

different expressions have been derived for this loss for different forms of surfaces. Those developed by Peclet are given in Box's treatise on Heat.

The rules given for convection in the text-books on heat cannot, as a rule, be applied to the loss of heat from buildings. All these rules assume that the air surrounding the object is in a perfectly quiescent state. In buildings this is not the case, for the air surrounding a building is rapidly circulated by the winds. Theoretically a high building would lose proportionally less heat than a low building, because in the upper stories there would be a smaller difference in temperature between the air inside the room and the air outside than in the lower stories. This, however, is not the case, as the wind circulates the air outside the building and makes the temperature of the air surrounding the building on the outside practically the same at all levels.

Inside the room, however, the air at the top of the room is much warmer than that at the floor. The result is that the rate of transmission of heat in rooms with high ceilings is appreciably higher than in rooms with low ceilings, as in the room with a high ceiling we have a greater difference of temperature between the inside and the outside air at the ceiling. This difference is not ordinarily considered unless the height of the room exceeds ten feet. If the height of the room does not exceed ten feet the temperature taken five feet above the floor line may be assumed as the average temperature of the room.

The loss of heat from buildings was first investigated both experimentally and theoretically by Peclet. The greater part of his work is given in Box's treatise

on Heat. The results obtained by Peclet are difficult to apply practically and nearly all the rules that are used to determine the loss of heat from a building are largely empirical. The constants determined by the German government are probably the most reliable we have.

The German formulas and tables were translated by J. H. Kinealy and published under the title "Formulas and Tables for Heating," by the "Metal Worker." The following pages outline the German method as given in the pamphlet mentioned.

In the simplest form of building the walls consist of one solid piece of the same material and in this case the transmission of heat is from the air of the room to the wall by convection, through the wall by conduction and from the surface of the wall to the cold air outside by convection. Such a wall is shown in Fig. 4.

A solid wall may be made up of a series of layers of different materials, as shown in Fig. 5. The transmission of heat, however, goes on in the same way.

In a wall such as is shown in Fig. 6, the heat passes through each of the consecutive walls just as it does through a solid wall. Heat always passes from a warmer to a colder body. Hence t_1', the temperature of the inside of the wall, must be less than the temperature of the room t, and the temperature t_0' must be greater than the temperature of the outside of the wall t_0'. Each particle in a section of the wall must have a different temperature, the temperature diminishing as the particle is nearer and nearer to the outside wall.

The quantity of heat transmitted through a given area of wall must be the same for each point in the sec-

tion when the wall has once reached a stable condition. The quantity of heat which passes per hour from the warm air of the room to a square foot of wall will be in Figs. 4, 5 and 6 a_1 (t_1—t_1'), and the heat which passes from the outside wall to the cold outside air is a_0 (t_0'—t_0). If the wall has an air space as in Fig. 6, the heat which passes to the air space will be a_1'(t_2'—

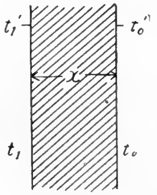


FIG 4

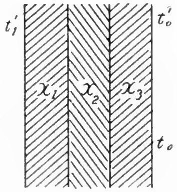


FIG. 5

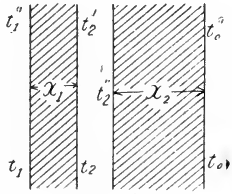


FIG. 6

t_2), and the heat given by the air space to the outer wall will be a_2'(t_2—t_2'').

The heat that passes through the wall by conduction, as stated before, will be in Fig. 4 $\frac{e}{x}$ (t_1'—t_0'), and in Fig. 6 for the inner wall $\frac{e_1}{x_1}$ (t_1'—t_2'), and for the outer wall $\frac{e_2}{x_2}$ (t_2''—t_0'). If the layers of this wall are of similar material, e_1 and e_2 will be equal.

In order to use these expressions it is necessary to know the temperature of the wall surface. These temperatures are not known. The only known temperatures are the temperature of the air inside the room and the air outside the building. Let us assume that the heat

transmission through the wall may be represented by the expression k $(t_1 - t_0)$, where k is a constant to be determined.

The amount of heat passing through the wall at each point is constant, hence we have for Fig. 4:

$$K (t_1 - t_0) = a_1 (t_1 - t_1') = a_0 (t_0' - t_0) = \frac{e}{x} (t_1' - t_0') \quad (1)$$

and for Fig. 6:

$$K (t_1 - t_0) = a_1 (t_1 - t_1') = a_1' (t_2' - t_2) = a_2' (t_2 - t_2'') = a_0 (t_0' - t_0)$$

$$= \frac{e_1}{x_1} (t_1' - t_2') = \frac{e_2}{x_2} (t_2'' - t_0') \quad (2)$$

Solving for k in equation (1)

$$K = \frac{1}{\frac{1}{a_1} + \frac{1}{a_0} + \frac{x}{e}} \quad (3)$$

and in equation (2)

$$K = \frac{1}{\frac{1}{a_1} + \frac{1}{a_1'} + \frac{1}{a_2'} + \frac{1}{a_0} + \frac{x_1}{e_1} + \frac{x_2}{e_2}} \quad (4)$$

For thin glass or thin metal walls, $\frac{x}{e}$ is a very small quantity and may be neglected.

The values of a and e must be known before k can be determined. The value of the convection factor, a, is determined by Grashof by the following equation:

$$a = c + d + \frac{(40\,c + 30d)\,T}{10{,}000}$$

c as a factor depends on the condition of the air, whether at rest or in motion. Rietschel gives the following values for c:

TABLE IV. VALUES OF c.

	c.
Air at rest, air in rooms	.82
Air with slow motion, air in rooms in contact with windows	1.03
Air with quick motion, air outside of a building	1.23

d is a factor depending upon the material composing the wall and on the condition of the surface. The values for d may be taken as follows:

TABLE V. VALUES OF d.

Substance.	d.	Substance.	d.
Brickwork	.74	Sheet iron	.57
Mortar and similar materials	.74	Sheet iron polished	.092
Wood	.74	Brass polished	.053
Glass	.60	Copper	.033
Cast iron	.65	Tin	.045
Paper	.78	Zinc	.049

T is the difference between the temperature of air and that of the surface of the wall. For poor conductors or very thick walls it may be taken as zero.

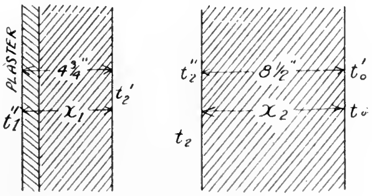


FIG 7

In approximate calculations it is usually taken as zero. The following values of T are given by Rietschel:

TABLE VI. VALUES OF T.

Brick work 5 inches thick	14.4
Brick work 10 inches thick	12.6
Brick work 15 inches thick	10.8
Brick work 20 inches thick	9.0
Brick work 25 inches thick	7.2
Brick work 30 inches thick	5.4
Brick work 40 inches thick	1.8
For single windows	36.
For double windows	18.
For wooden doors	1.8

Table VII gives values of e. These values vary considerably for different authors.

TABLE VII. VALUES FOR e.

	e.
Brick work	5.6
Mortar, plaster	5.6
Rubble masonry	14.

Limestone	15.
Marble, fine grained	28.
Marble, coarse grained	22.
Oak across the grain	1.71
Pine, with the grain	1.4
Pine, across the grain	.76
Sandstone	10.
Glass	6.6
Paper	.27

For example, assume a brick wall as shown in Figure 7. There are four air contact surfaces and two walls through which conduction takes place, then:

K is the same as in equation 4.

Rietschel assumes a_1', a_2'' and a_0' equal and he uses the same value of T as for a solid of thickness equal to the brick work without the air space.

$$a_1 = a_1' = a_0' = .82 + .74 + \frac{(40 \times .82 + 30 \times .74)10}{10,000} = 1.62$$

$$a_0 = 1.23 + .74 + \frac{(40 \times 1.23 + 30 \times 74)10}{10,000} = 2.04$$

Since both walls are of brick work

$$\frac{X_1}{e_1} = \frac{4.75}{5.6} = .85$$

$$\frac{X_2}{e} = \frac{8.25}{5.6} = 1.47$$

Substituting in equation (5)

$$k = \frac{1}{.62 + .62 + .62 + .49 + .85 + 1.47} = .214$$

Making this same calculation, neglecting T gives

$$k = .210$$

The following values of k have been determined by using equations (3) and (4) as shown in the example.

TABLE VIII. VALUES OF k ADOPTED BY PRUSSIA.

Brick work.	k.	Masonry, sandstone.	k.
4.72 inches thick.........	.492	11.8 inches thick..........	.451
9.85 inches thick.........	.348	15.7 inches thick..........	.39
15 inches thick.........	.266	19.7 inches thick..........	.348
20.1 inches thick.........	.226	23.8 inches thick..........	.318
25.2 inches thick.........	.184	27.6 inches thick..........	.287
30.2 inches thick.........	.164	31.6 inches thick..........	.266
35 inches thick.........	.133	35.4 inches thick..........	.246
40.5 inches thick.........	.123	39.4 inches thick..........	.226
45.6 inches thick.........	.113	43.3 inches thick..........	.205
		47.2 inches thick..........	.195

For limestone masonry the values of k should be taken 10% larger than those given for sandstone.

TABLE IX.

Values of k for various forms of brick walls. Brick are assumed 8¼x4x2, laid with ⅜-inch mortar joints. Plastering ¾ of an inch thick.

	Outside Walls.			Inside Walls.	
Thickness of Wall.	No Plaster.	One Side Plastered.	One Side Plastered and 2.4 Air Spaces in the Wall.	Plaster Board and Air Space Between Wall and Board.	Plastered Both Sides.
	k	k	k	k	k
½ brick	.52	.49	..	.29	.43
1 "	.37	.36	.25	.24	.33
1½ "	.29	.28	.21	.21	.26
2 "	.25	.24	.19	.20	..
2½ "	.22	.21	.16	..	..
3 "	.19	.18	.14	..	..
3½ "	.16	.16	.13	..	..
4 "	.14	.14	.12	..	..
4½ "	.12	.12	..	..	..

For doors, wooden walls and windows, the values of k are given in Tables X, XI and XII.

TABLE X. DOOR OR WOODEN WALLS.

	Pine		Oak	
Thickness—	Inside.	Outside.	Inside.	Outside.
	k	k	k	k
½ inch	.52	.56	.64	.70
¾ inch	.44	.47	.59	.63
1 inch	.39	.41	.54	.58
1¼ inch	.34	.36	.50	.54
1½ inch	.31	.32	.47	.50
2 inch	.26	.27	.41	.43

TABLE XI. WINDOWS AND WALLS.

Single window	1.03
Single window, double glass..............................	.62
Double window	.46

Single skylight	1.16
Double skylight	.48
Stud partition, lath and plaster one side	.60
Stud partition, lath and plaster both sides	.34
Lath and plaster ceiling space above unheated	.62
Floor ¾ inch thick, cold space below	.45
Floor ¾ inch thick, lath and plaster on under side, cold space below	.26
Floor double 1½ inches thick, cold space below	.31
Floor double 1½ inches thick, lath and plaster on under side, cold space below	.18

TABLE XII. OUTSIDE WALLS.

Walls having lath and plaster on the inside, and outside is covered as described.

Outside covering—	k.
Overlapping clapboard 7-16 inch thick	.44
Paper and clapboards	.31
¾ inch sheathing and clapboards	.28
¾ inch sheathing, paper and clapboards	.25

Factors for Exposure.—The heat losses given in the tables should be increased as follows: Where the room has a north or northwestern exposure and the winds are severe, add 20 to 30 per cent. When the building is heated in the day time only and allowed to cool during the night, add 20 per cent. When the building is heated occasionally—for example, a church—add from 40 to 50 per cent. Where a room has a northerly exposure and is subjected to extremely high winds, add 30 per cent. It is usually advisable to assume for unwarmed spaces, such as cellars and attics, a temperature of about 32°. For vestibules and entrances unheated, which are being frequently opened to the outer air, a temperature of 20° may be assumed.

Determination of the Loss of Heat from a Building.—In determining the loss of heat from a building all surfaces should be considered which have on the outside a lower temperature than the temperature in the room. If a room is situated over a portion of the cellar which is not heated, the loss of heat through the floor should be considered. If the room has over it an unheated attic the loss through the ceiling should

be considered. In most cases where the attic has no window it is warm enough so that the heat loss through the ceiling may be neglected. The loss through the sides of a room which is surrounded by rooms at the same temperature may be neglected. Doors entering directly into a room from outside are roughly considered to lose the same amount of heat per square foot as windows.

Rules for Determining the Loss of Heat.—A common rule for the loss of heat from a building is that given by Professor R. C. Carpenter in his book on "Heating and Ventilation." This rule is developed from the following consideration: Referring to Table IV, we notice that one square foot of glass conducts approximately four times as much heat as a brick wall 20 inches thick. If, then, we divide the wall surface by 4, the result will give us the number of square feet of glass surface, which would lose the same quantity of heat. Adding to this the actual glass surface would give us the total equivalent glass surface. In addition to this heat transmitted through the walls we must add the heat which is lost by the air which passes directly through the walls themselves. It is assumed that for ordinary sized rooms the air in the room will be changed about once an hour, so that we must figure on heating the entire air in the room about once per hour. One cubic foot of air weighs, approximately, 1/13 of a pound. To raise a pound of air one degree requires .238 B. t. u. Then to raise one cubic foot of air one degree would require $.238 \times 1/13 = .0183$ B. t. u. or one heat unit will heat $1 \div .0183 = 54.6$ cubic feet, or in round numbers say 55. If, then, we divide the contents of a room by 55 we

will have the heat lost by filtration through the walls. Adding these factors together will give the total heat lost from the room. This rule may be expressed more concisely as follows:

RULE 1.—*Divide the contents of the room by* 55; *add the glass surface and add to this sum the wall surface divided by* 4. *The sum will be the heat lost from the room per degree difference of temperature between the air in the room and the air outside the room. Multiply this sum by the difference in temperature between the air inside the room and that outside of the room and the product will be the heat lost from the room.*

This rule can be expressed algebraically as follows:

Let C represent the volume of the room, W the wall surface, G the glass surface and d the difference of temperature between the air outside and the air inside the room. The heat loss from the room per hour expressed in B. t. u.'s would be $\left\{ \frac{Cn}{55} + \frac{W}{4} + G \right\} d$, *where n is a factor which depends upon the tightness of the room and varies in value from* 1—3. *For ordinary room* $n=1$, *for corridors* 1.5, *for vestibules* 2 *to* 3.

It is quite customary to assume the difference in temperature between the air in a room and the air outside to be 70°. Where the windows are poorly fitted or the house loosely built the loss by filtration should be doubled, and in halls where the doors are being opened and closed frequently this should be multiplied by three.

There is one criticism on this method of figuring the heat loss in the room. The diffusion loss is assumed to depend upon the cubic contents of the room.

This of course is manifestly not correct, as the diffusion loss occurs through the walls and windows and must depend upon the area of the walls and windows. The rule, however, will work very well for rooms of average size, but where the rooms have excessive wall and window surfaces, or where the cubic contents of the room is large compared to the wall and window surfaces, this rule will give inconsistent results. The following rule seems to the author to be capable of a much wider application:

RULE 2.—*Divide the wall surface by 4; add the glass surface; multiply this sum by the difference in temperature between the air in the room and the air outside, and then multiply the result by 1½. This rule is for a well constructed building. If the building is old and poorly built then instead of multiplying by 1½ the result should be multiplied by 2; entrance halls multiplied by 2½.*

This rule may be expressed algebraically as follows:

Let W represent the wall surface, G the glass surface, and d the difference of temperature between the air outside and the air inside the room. Then the heat loss from the room per hour expressed in B. t. u.'s would be $\left\{ \frac{W}{4} + G \right\} d\, n$, *where n is a factor which depends upon the construction of the house or location of the room and varies in value from 1.5 to 2.5, as stated above.*

In figuring the radiating surface for any room the cubic contents should always be taken into consideration. In a large room with a small exposed wall surface, if only enough radiation is put in to cover the loss from walls and windows, the room will be slow to heat. In addition to taking care of the loss from walls and win-

dows it is necessary for the radiator to heat the air in the room itself. In order to do this a large proportion of this air must either pass through the heating device or be carried out by the ventilating flues, so that where the cubic contents of a room is large it is advisable to add from 10 to 20 per cent to the radiating surface to allow for the heating of the air in the room itself. The above remark applies only when the building is intermittently heated; when the building is continuously heated it is not necessary to consider the volume of the room.

The following temperatures are usually assumed in determining the heat losses:

TABLE XIII. TEMPERATURES ASSUMED IN HEATING.

	Degrees.
Temperature of stores	68
Temperature of residences	70
Temperature of halls and auditoriums	64
Temperature of prisons	65
Temperature of factories	60 to 68
Temperature of cellars not warmed	32
Temperature of outside entrances	20
Temperature of attics not warmed	32

The average temperature for the period of the year during which buildings are heated throughout the Cen-States may be assumed to be approximately 35°.

The following examples will show the method to be pursued in determining the heat lost from a building:

Example 1.—Suppose a room, as shown in Fig. 8. Let the temperature be maintained in the room at 70 degrees, the temperature of the outside air be 0. Let the walls be of brick, 8 inches thick, plastered on plaster board on the inside, the windows be 2½x6 feet, the ceiling of the room be 10 feet high. Let the room be on the second floor of the building, the rooms above and below heated. The window surfaces are 2x2½x6=30

square feet. The total wall surface is 20x10=200 square feet. The net wall surface is 200—30=170 square feet. Then the heat lost from the room per degree difference

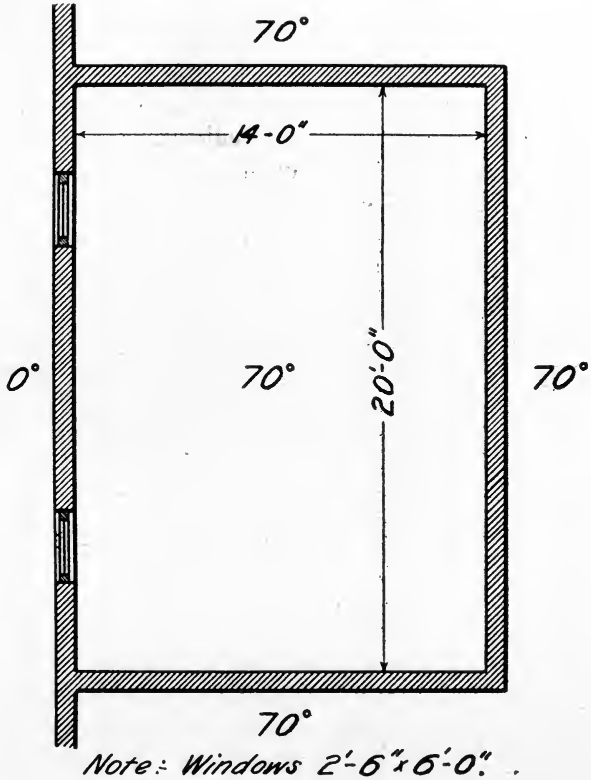


Fig. 8.

of temperature by rule 2 would be 170÷4+30=72½. As the difference between the outside and inside temperature is 70°, the total heat lost is 72½x70=5,075 B. t. u. per hour.

Example 2.—Take the same room as Example 1, except that the room is covered by a flat tin roof. The air space between the ceiling of the room and roof should be assumed to be at a temperature of 32°. Then, in addition to the loss figured in Example 1, there will have to be added the loss due to the tin roof. The area of the ceiling of the room would be 14x20=280 square feet. Referring to Table IV we find the loss per hour through ceilings of plaster construction to be .62 B. t. u. per degree difference of temperature; then the loss through this ceiling would be, per degree of temperature, .62×280=173.6 B. t. u. The room being at 70° and the attic space 32°, the difference in temperature would be 70—32=38 degrees. The total loss through the ceiling would then be 29.1×38=6,574 B. t. u. Adding this to the loss found in Example 1 we have a total loss from the room, 5,075+6,574=11,649 B. t. u.

A more accurate method is to figure the actual loss through the walls and windows from the constants in tables IX and X.

The loss from walls (.24×170) 70=.............2,856
The loss from windows (1.03×30) 70=..........2,163

Total loss from walls and windows=........5,019

To allow for diffusion this sum must be multiplied by 1½, making a gross loss of 7,528.

CHAPTER II.

DIFFERENT FORMS OF HEATING.

Classification of Heating Apparatus.—The different heating systems may be classed under two general heads—Direct and Indirect. In direct heating the heating surfaces are placed in the rooms to be heated, as, for instance, stoves, steam radiators or hot water radiators. In indirect heating systems the heating apparatus is placed in some other room and the heat carried to the room to be heated by means of pipes. Under this head would be included hot air furnaces and the various systems of heating in which fresh cold air is made to pass over steam or hot water radiators on its way to the room.

The indirect systems of heating naturally divide themselves into two other classes, those using natural draft and those using forced draft. A good example of natural draft indirect heating is the hot air furnace, where the circulation of air through the house is produced by the difference in temperature between the air in the hot air flues and the cold air outside the flues. The fan system of heating, used in heating school buildings and churches, are good examples of the forced draft system. In this case the draft is largely produced by mechanical means, usually a disc fan or a pressure blower.

In order to understand better a discussion of the various forms of heating which will come later, it is desirable to understand in general the advantages and disadvantages of the various forms of heating.

Grates.—The most primitive form of heating ap-

paratus is the grate. In the grate the air which passes through the fire and is heated by the fire all passes up the chimney and only the heat given off by radiation to the walls and objects in the room is effective in heating the room. In grates of better construction this is somewhat improved by surrounding the grate by fire brick so arranged that the brick will become highly heated and radiate heat to the room. But the fact that all the air heated by the grate passes up the stack makes this a very uneconomical form of heating. In the best form of open grates only about 20 per cent of the heat of the fuel is effective in heating the room. This form of heating, however, has been defended by many. It is a very popular form of heating throughout England and Scotland. The feeling of a grate-heated room is quite different from that of a room heated by other systems. All the heat is given off by radiation and the air in a grate-heated room is at a considerably lower temperature than the objects and persons in the room, owing to the fact that radiated heat does not heat the air through which it passes. The air of the room being at a lower temperature, its capacity for moisture is not increased as much as it would be were the air heated to a higher temperature. The result is that the air contains proportionally more moisture than is the case in other forms of heating. This, no doubt, is an advantage. On the other hand, it is impossible to heat the room uniformly, and a person is hot or cold, depending upon his distance from the grate. Heating by means of grates is practiced only in the more moderate climates. The grate is useful in the houses heated by other forms of heating, as it serves as a most efficient foul

air flue. The introduction of a large number of grates into a house adds materially to the ease with which the house may be ventilated.

Stoves.—The stove is a marked improvement over the grate as a form of heating, particularly from the standpoint of economy. The modern base burner stove is one of the most economic and efficient forms of heating, making use of from 70 to 80 per cent of the heat in the fuel. In heating by a stove the heat is given off both by radiation and by convection. The hot surface of the stove being at a higher temperature than the surrounding objects in the room, radiates its heat directly to these objects. In addition the air surrounding the stove is heated and rises, passing along the ceiling to the cold wall and window surfaces where it is cooled, drops to the floor and passes along the floor back to the stove to be again heated. In selecting a stove to heat a given room care should be taken to select one of ample size so that only in the coldest weather would it be necessary to crowd it; that is, keep on the drafts in order to heat the room. At the present time the stove as a general source of heat is being rapidly discarded because of the attendance required, the space occupied and the unsightly appearance of the stove. Another serious objection to the stove is the fact that it does not furnish ventilation to the room which it heats.

Hot Air Furnaces.—The hot air furnace is a natural outgrowth of the stove. In this system one large stove is placed in the basement of the building, the air is taken from the outside, passed over the surfaces of the stove or furnace, carried up through the flues to the rooms to be heated. The principal ad-

vantage of the hot air furnace is that it provides a cheap method of furnishing both heat and ventilation, it requires little attendance and does not deteriorate rapidly when properly taken care of. The greatest disadvantage of this system is in the fact that the circulation of the heated air depends entirely upon natural draft; that is, it depends upon the difference in weight between the air inside the flue and the air outside the flues. This difference of weight is extremely small, so that the force producing circulation in the flue is always small. This force is easily overcome either by the winds or by the resistance of the piping. When a very strong wind blows against one side of the house it is difficult to heat the rooms on that side of the house. If the system is carefully designed, however, this difficulty can be overcome in a measure. Another serious objection to the hot air furnace is that it is seldom dust tight and dust and ashes are carried into the room. In general, however, the hot air furnace may be considered as a very good type of heating plant for small residences.

In the case of the hot air furnace the heat is carried to the room by convection, as all heat is carried from the furnace by the air which passes around the furnace and enters the rooms from the flues. This air circulates in the room and heats the objects and air in the room. The efficiency of the hot air system will vary, depending on the relative proportion of the air taken from outside and upon the temperature of the air entering the room. If the cold air entering the furnace is taken from the house itself and not from outside, the efficiency of the hot air furnace will be almost the same as that of a steam furnace; that is,

from 70 to 75 per cent of the heat of the coal will go into the rooms. If, however, the cold air is taken from outside, then the heat used in heating the air from the temperature of the outside air to the temperature of the room will be lost, and under ordinary conditions of operation the efficiency would be from 50 to 60 per cent.

Steam Heating Direct.—From the standpoint of ventilation direct steam heat has little advantage over a stove, as it gives no means of supplying fresh air. Its use in general should be confined to rooms which require little or no ventilation. Mechanically, however, it has many advantages over the stove or the hot air furnace. The boiler for a building having this form of heating can be located anywhere in the basement, and the rooms are free from dirt or gas. The modern radiator is easily adapted to almost any location in the room, it is not affected by wind or local conditions, and a distant room may be heated as easily as one close to the furnace. The efficiency of the direct steam heating system is less than that of a stove, with a well-installed plant from 60 to 70 per cent of the heat of the fuel will be delivered by the radiator to the room.

Hot Water, Direct.—The application of direct hot water radiators as a method of heating is similar to that of steam, with the exception that the surfaces are at a much lower temperature and hence more radiating surface will be required. It has an advantage over steam in that the temperature of the heating surface can be controlled easily, and can be anywhere from the temperature of the room to 180 degrees. It also has the advantage that the surface

of the radiator being at a lower temperature gives off more heat by convection and less by radiation. This gives the room more nearly the condition of Summer and the heating is not apparent to the occupants of the room. In the steam radiator the surface is usually not less than 212 degrees. The principal disadvantage of this system is in the fact that the circulation of the system is by natural circulation; that is, the circulation is produced by a difference in weight between the water in the hot leg of the system and in the cold leg of the system. This difference in temperature is usually about 10 degrees, so that the difference in weight between these two columns of water is small and the resulting force producing circulation is, of course, small. It is necessary to be very careful in designing the piping for the hot water system, as the circulation may be easily affected by the height of the radiator above the boiler; the greater the height above the boiler, the greater will be the difference in weight between the two columns of water and the stronger will be the force producing circulation. This system in general requires more careful design and construction than the steam system. The efficiency of the hot water system is practically the same as that of steam, and we may expect to obtain in the room from 60 to 70 per cent of the heat in the coal.

Indirect Steam Heating.—In heating with indirect steam radiation cold air is drawn from the outside, passed through and around the hot radiator, which is usually situated in the basement, and delivered by pipes to the rooms to be heated. The rules governing the introduction of air into the rooms and the method

of running pipes is similar to that employed with hot air furnaces. The principal advantages of indirect steam over hot air are: Each room has a separate source of heat, the system is not affected by the winds and no dust or obnoxious gases are carried to the rooms.

The air entering the room will always be as pure as the air which furnishes the source of supply. The source of heat being independent of the position of the boiler, it is possible to place the indirect radiator anywhere in the building and long hot air pipes are not necessary. This makes the indirect radiator much more efficient and more certain in operation than the hot air furnace. The efficiency of this system, from the standpoint of coal consumption, will be much less than in direct forms of heating and about the same as the hot air furnace; that is, from 50 to 60 per cent of the heat of the coal will be used effectively in heating.

Indirect Hot Water Heating.—The application of hot water indirect is similar to that of steam and the efficiency is practically the same. The use of hot water indirects has been much more limited than the use of steam indirects. The installation of hot water indirects must be done with great care so that each radiator will at all times have the proper amount of hot water circulation through it. In the hot water indirect radiators, if for any reason the water in the radiator becomes cooled, the radiator will be in danger of freezing. In mild climates this difficulty would not be as serious as in locations where the weather is extremely cold.

Fan System of Heating.—In buildings of a public or semi-public character, where a large number of

people are to be assembled in a relatively small space, it is necessary to provide adequate ventilation. In the systems that have been previously described it is impossible to introduce into the room sufficient quantities of air to ventilate the rooms properly. It may be said in general that no system of natural circulation has ever produced satisfactory ventilation in a room occupied by a large number of people; it is necessary to provide some means of mechanically circulating the air. This is done in the fan system by means of a pressure blower or a disc fan.

In the fan system the pressure produced by the fan makes the circulation so positive that it is not affected by winds or by the distance of the room from the fan itself. The air is taken from the outside, passed through the heating coils and forced into the building by the fan.

There are two general methods of heating and ventilating with the fan system. In one system the air is first passed through a tempering coil, then taken by the fan and delivered through a heating coil. Each room has a connection both to the hot air and to the tempered air chamber. The temperature of the air in the room is adjusted by taking the air either from the hot air chamber or from the tempered air chamber. In the second system the rooms themselves are heated by means of direct radiation and the fan delivers air to the rooms only for the purpose of ventilation. In this case no heating coils would be necessary.

In the first method the economy of the system is low, as owing to the large amount of air required for ventilation and the quantity of air introduced into

the room is ordinarily greater than is necessary for the purpose of heating the room. The economy of this form of fan system depends very largely upon the amount of air necessary, but in most cases its efficiency would not exceed from 40 to 50 per cent; that is, only 40 to 50 per cent of the heat units in the coal would be effective in heating. In the combined fan system, where direct radiation is used for heating and the fan system for ventilation, the economy of the system is better, probably from 50 to 60 per cent.

The increase in economy of this system is due to the fact that it is necessary to run the fans only when it is necessary to ventilate the building.

Combination of Different Systems.—In addition to the combination just described, of direct radiation and fan ventilation, there have been devised innumerable combinations, combinations of direct and indirect steam, direct and indirect water, water and hot air, steam and hot air. Probably the combinations which have been most used have been combinations of direct and indirect steam and the combinations of hot water and hot air.

The Economy of Different Systems.—The economy of any heating system depends upon the completeness with which the coal in the furnace is burned and the heat lost by the chimney and the ventilating flues. If, with each of the above systems the coal was completely burned and all the heat given off were used, then each one of the systems would have perfect efficiency.

The losses from any system, given in detail, are as follows: *Loss through imperfect combustion of coal, through the escape of hot gases up the chimney and the*

loss of heat in the air passing up the ventilating flue.

If the furnace is properly constructed and insures good combustion, the loss due to imperfect combustion is small. The loss of heat passing up the chimney will depend upon the temperature at which the gases leave the chimney and the amount of air used to burn a pound of coal. The loss by the ventilating flue will depend upon the amount of air it is necessary to supply to the rooms for ventilation.

If the hot gases leave the heating apparatus at the same temperature and the same amount of air is used for ventilation, then the efficiency of each system will be practically the same. If the rooms are not ventilated, then, of course, the loss due to the heat passing up the ventilating flues will be saved and the system will be more economical. In fact, strictly speaking, the loss by ventilation should not be considered as entering into the efficiency of the system. This loss is entirely independent of the system used and depends entirely upon the amount of air which must be supplied for purpose of ventilation. It is quite obvious that any system involving ventilation will require a greater amount of coal. The loss due to ventilation is due to the fact that all the heat which is given to the air between the temperature of the air outside the building and the air in the room is ineffective in heating and is lost up the ventilating flues. It would be poor policy, however, for the designers of heating systems to cut down the amount of ventilation in a room in order to save coal. In several states there are general state laws which require that a certain amount of air be furnished each person per hour in school buildings and other buildings of a public character. The necessity and importance of ventilation will be discussed under another head.

CHAPTER III.

THE DESIGN OF A DIRECT STEAM-HEATING SYSTEM.

Steam heating is usually done by direct or by indirect radiation or by combination of both direct and indirect radiation. In small residences occupied by only three or four persons it is customary to use only direct radiation. The practice, however, is a questionable one, and it seems desirable, even in small residences, that some indirect radiation be used so as to provide a means of ventilation. Oftentimes only one indirect radiator is used, bringing its air either into the room most used or into the main hall so that it may be distributed throughout the house. In factories and office buildings where a large amount of air is introduced by the opening and closing of doors it is customary to use only direct radiation, and in such buildings this is permissible.

Nature and Properties of Steam.—In order to understand thoroughly the operation of a steam heating system the nature and properties of steam should be studied. Steam is a watery vapor, and as used in ordinary radiator practice always contains a certain amount of water in suspension, as does the atmosphere in foggy weather.

When water is heated in a steam boiler the temperature is slowly increased from the initial temperature of the water to the temperature of the boiling point. When the water reaches the boiling point small particles of the water are changed from water to steam, rise through the mass of water and escape to the surface; the water is then said to boil. The temperature at which the water boils depends entirely upon the pressure in the boiler and

obviously, as the boiling point increases more and more, heat is required to produce steam.

Take, for instance, a given case. Suppose we start with water in the boiler at 40 degrees and the pressure in the boiler at atmospheric pressure, that is, 14.7 pounds. Under this condition it will be necessary to increase the temperature of the water in the boiler to 212 degrees, at which point water will commence to boil. It will be necessary to add 212—40=172 B. t. u. for every pound of water in the boiler. In order to convert all the water into steam it will be necessary to supply 965.7 heat units for each pound, in addition to the 172 heat units consumed in raising the water to the boiling point. During the operation of boiling, however, the temperature of the water remains constant and the 966 heat units added in order to change the water at the temperature of the boiling point into steam are consumed in separating the molecules of water and changing the water from a liquid into a gas. This last quantity is termed the *latent heat* and it is the latent heat of water which is used primarily in furnishing heat to the room in steam heating. As the pressure in the boiler increases the latent heat diminishes. The relation of these various quantities has been very carefully determined by Regnault and compiled in the form of steam tables. The following is an abbreviated steam table. More complete tables will be found in Peabody's Steam Tables, or in any of the mechanical engineering handbooks.

STEAM TABLES.

Column 1 of the Steam Table gives the pressure of the steam above the atmosphere in pounds per square inch and below the atmosphere in inches of mercury. Column 2 gives the corresponding temperature of the steam.

Column 3 gives the heat of the liquid or the heat necessary to raise one pound of water from 32 degrees to the temperature of the boiling point, corresponding to the pressure. Column 4 gives the latent heat necessary to change a pound of water at the temperature of the boiling point into steam at the same temperature. Column 5 is the sum of columns 3 and 4, and represents the amount of heat necessary to raise a pound of water from 32° to the boiling point and then change it into steam at the temperature of the boiling point. The quantities given in this column are called total heat. Column 6 gives the volume of one pound of steam at the different pressures.

TABLE XIV—PROPERTIES OF STEAM.

Pressure or Vacuum. Inches Mercury	Temperature	Heat of the Liquid	Latent Heat	Total Heat	Volume of 1 lb. of Steam
—24	137	105	1,019	1,124	135
—20	160	128	1,003	1,131	78.3
—16	175	143	992	1,135	55.9
—14	187	155	984	1,139	43.6
— 8	197	165	977	1,142	35.8
— 2	205	173	971	1,144	30.6
Pounds per sq. in.					
0	212	180.9	965.7	1,146.6	26.36
1	215	184	964	1.148	25
2	219	188	961	1,149	23
3	222	191	959	1,150	22.3
4	224	193	957	1,150.5	21.2
5	227	196	955	1,151	20.16
10	239	208	946	1,154	16.3
15	249	218.8	939.3	1,158.1	13.7
20	258.7	228	932.5	1,161	11.85
25	266.7	236.2	927.1	1,163.3	10.36
30	273.9	243.5	922	1,165.5	9.34
35	280.5	250.2	917.3	1,167.5	8.45
40	286.5	256.3	913	1,169.3	7.73
45	292.2	262.1	909	1,171.1	7.11
50	297.5	267.5	905.2	1,172.7	6.61
55	302.4	272.6	901.6	1,174.2	6.16
60	307.1	277.2	898.4	1,175.6	5.77
65	311.5	281.8	895.1	1,176.9	5.43
70	315.8	286.1	892.1	1,178.2	5.13
75	319.8	290.3	889.1	1,179.4	4.86
80	323.7	294.3	886.3	1,180.6	4.63
85	327.4	298.1	883.6	1,181.7	4.41
90	330.9	301.8	881	1,182.8	4.20
95	334.4	305.4	878.5	1,183.9	4.02
100	337.6	308.9	876	1,184.9	3.83
110	343.9	315.4	871.4	1,186.8	3.57
120	349.8	321.5	867.1	1,188.6	3.33
130	355	327.5	863	1,190.3	3.1
140	360	333.5	859.1	1,191.9	2.92
150	365.7	338.3	855.4	1,193.4	2.75

EXAMPLES IN USE OF STEAM TABLE.

EXAMPLE 1.—It is required to convert 10 pounds of water at 32° into steam at 100 pounds gauge pressure.

SOLUTION.—We see from column 5 that the total heat of 1 pound of steam at 100 pounds pressure is 1,184.9 heat units. Then to form 10 pounds of steam would require 10 times this amount, of 11,849 heat units.

2. How many heat units will be required to form 5 pounds of steam from feed water at 100° in temperature into steam at 10 pounds gauge pressure?

SOLUTION.—The total heat of steam at 10 pounds pressure above 32° is 1,154 heat units. In this case the feed water already contains in it above 32°, $100 - 32 = 68$ heat units. The specific heat of water being 1, the heat units required to form a pound of steam will be $1{,}154 - 68 = 1{,}086$, and to form 5 pounds of steam would require $5 \times 1{,}086 = 5{,}430$.

3. A steam pipe is 8 inches in diameter. The pressure of steam in the pipe is 10 pounds gauge. The steam pipe is to transmit 1,600 pounds of steam per hour. What will be the velocity of steam in the pipe?

SOLUTION.—From column 6 of the table we see that the volumn of 1 pound of steam at 10 pounds gauge pressure is 16.3 cubic feet. Then $1{,}600 \times 16.3 = 26{,}080$ cubic feet, the volume of steam passing per hour. This divided by 3,600 equals 72, the number of cubic feet passing per second. An 8-inch pipe has an area of 50 square inches; $50 \div 144 = .347$ square feet; $72 \div .347 = 208$ feet per second, which represents the velocity of the steam passing through the pipe. This velocity is very high. Ordinarily the velocity in steam pipes should not exceed 100 feet per second, even in very large pipes.

LOSS OF HEAT FROM RADIATORS.

In designing a direct steam system it will be necessary first to compute the heat losses from the various rooms by the rules previously given. After these losses are determined it will be necessary to place sufficient radiating surface in the room to supply these losses. In order to know the amount of surface that should be placed in a room it is necessary to know the amount of heat given off per square foot by the different forms of radiators. Heat losses for the different forms of direct radiators are given in the following table:

TABLE XV—LOSS FROM WROUGHT IRON PIPE AND CAST IRON RADIATORS.

Type of Radiator	No. of sq. ft. in radiator	Temperature of steam in radiator.	Temperature of the air in the room	No. lbs. steam condensed per sq. ft. per hour	B. t. u. per sq. ft. per hour per deg. diff. of temp. between steam and room
Cast Iron Radiators, 38 Inches.					
1 column	48 sq. ft.	226	105	.212	1.82
2 column	48 sq. ft.	226	76	.253	1.65
3 column	45.3 sq. ft.	226	88	.204	1.42
6 column	36 sq. ft.	225	71	.217	1.35
Wrought Iron Radiators, 38 Inches.					
1 column	12 sq. ft.	221	89	.446	3.27
2 column	42 sq. ft.	222	83	.284	2.
3 column	48 sq. ft.	229	70	.294	1.77
4 column	48 sq. ft.	226	73	.202	1.27
1" wall coil, 1 pipe high		212	70	.41	2.8
1" wall coil, 4 pipes high		228	65	.425	2.48
Colonial wall coil		212	70	.330	2.25

Column 5 is the column which shows the relative effectiveness of the various types of radiators. It is obtained in the following manner: Take, for example, the two-column cast iron radiators, results of which are given in line 2 of the table. A pound of steam at 226°, as we see from the steam tables, gives up its latent heat in condensing which amounts to 965 heat units. This radiator

condensed .253 pounds of steam per square foot of surface per hour. Then $965 \times .253 = 247$, the heat units given up by the radiator per square foot per actual surface per hour. The steam in the radiator was at a tem-

Fig. 9. Single-Column Cast Iron Radiator.

perature of 226° and the air in the room at a temperature of 76°, the difference in temperature being 150°. If we divide 247 by 150 the result is approximately 1.65. This result represents the B. t. u. transmitted per

square foot of rated surface per hour per degree difference of temperature between the steam inside the radiator and the air in the room. This is the quantity which should be used in comparing the relative merits of the various forms of heating surfaces.

The results of a series of experiments made at the

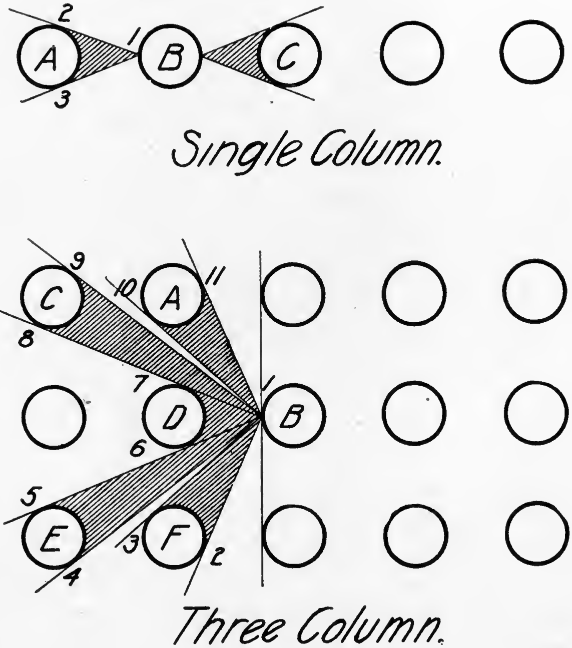


Fig. 10.

University of Michigan, extending over a period of a number of years, together with the results shown in the foregoing table, lead to the following conclusions:

Different Types of Relative Efficiency.—*Radiators with different steam volumes do not give essentially*

different results, except as the volume is so small as to restrict the passage of steam. Single column radiators, as shown in Fig. 9, usually show larger results than those with more than one column. The condensation per square foot of radiator per degree difference of temperature as shown in column 5 of Table VII shows a rapid decrease as the number of columns increases. The reason for this is quite apparent when we consider the position of the radiating surfaces in a single pipe radiator as compared with the surface in a three-pipe radiator. Referring to Fig. 10, tube B, you will note that this tube can radiate heat in all directions without interference, except those lines which radiate to columns A and C. Columns A and C being at the same temperature, no radiant heat passes between them, so that all the surface of column B which would radiate its heat to columns A and C is unaffected. The amount of surface which does this, however, is extremely small.

Suppose we take point 1 on column B. The heat from that point radiates in a straight line in all directions. But all the rays of heat between ray 2 and ray 3 strike on column A and are lost because column A is the same temperature as column B. The number of rays that do this are extremely small in a single column radiator.

If we consider column B in a three-column radiator and take point 1 on column B we see that all the rays between 2 and 3, 4 and 5, 6 and 7, 8 and 9, 10 and 11 are lost and become ineffective for heating as columns A, C, D, E, F, are at the same temperature and intercept rays passing into the room.

When the columns in a radiator have been increased from 5 to 6 then the inner columns have practically no effect in giving off radiant heat, and the only heat they

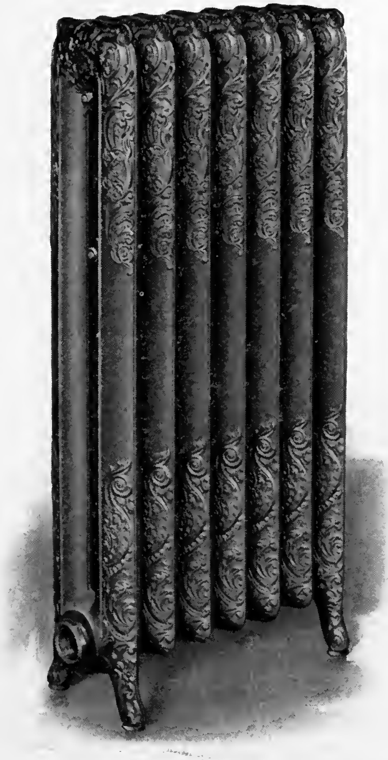


Fig. 11. Two-Column Cast Iron Radiator.

give off is given by convection due to the passage of air through the radiator.

By glancing at Fig. 10 we see that the greater the distance between the columns or pipes of a radiator the smaller would be the number of rays of radiant heat

intercepted by other columns of the radiator and the larger would be the radiating effect; the wider the space between the columns of the radiator the more effective does the radiator become in giving off heat.

The writer has had opportunity to make a series of tests on radiators of the two-column type, having the sections of one radiator spaced at 2½ inches and the sections of the other radiator 3⅛ inches. The increase of ⅝ inch in the length of space added approximately 10 per cent to the effectiveness of the radiator.

Radiators are made in standard heights. The height most used is 38 inches. They can be purchased, however, in varying heights from 15 to 45 inches. The radiators of various heights are rated at a certain number of square feet per section. For instance, a 38-inch two-column radiator, as shown in Fig. 11, is rated at 4 square feet per section. As a rule, however, radiators are slightly overrated. A radiator containing 48 square feet has an actual surface, when measured, of about 47 square feet in most two-column radiators. In some cases, particularly in radiators having a large number of columns, the radiators are very much overrated. In one instance a radiator rated at 36 square feet had an actual surface of only 27 square feet. In purchasing a radiator, therefore, it is important to know that it has approximately the surface given in the catalogue of the manufacturer, as the radiating power depends primarily upon the square feet of surface it contains.

Comparing lines 2 and 6 of Table XV you will notice that the two-column wrought iron radiator transmits about 20 per cent more heat than the two-column cast iron radiator. This is undoubtedly due not to the difference of material, but to the difference in the spacing

of the columns composing the radiators. Wrought iron pipe wall coil, as shown in the next to the last line of the table, condenses almost 50 per cent more steam than the cast iron radiator. The reason for this is not

Fig. 12. Three-Column Cast Iron Radiator.

so much the difference in material as the difference of location. In the case of the cast iron radiator the air at the base becomes heated, rises along the radiator, becoming more and more heated as it comes nearer to the top,

so that at the top of the radiator there is a smaller difference between the temperature of the air surrounding the radiator and the temperature of the radiator itself. This reduces the transmission of heat near the top of the radiator. In the wall coil, the sections being placed in a horizontal position, the air remains in contact with the coil for a short time only, so that the air surrounding all portions of the coil is practically at the same temperature. To state this in another way, in the cast iron radiator, with the sections placed vertically, the difference in tem-

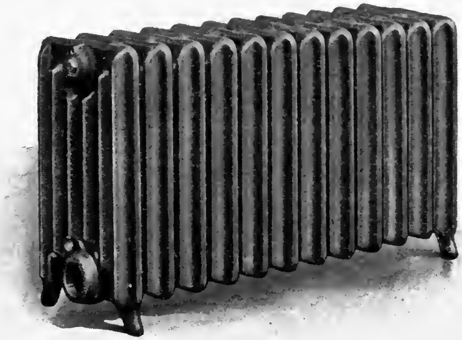


Fig. 13. Six-Column Cast Iron Radiator.

End View of Section.

perature between the air outside the radiator and the steam inside the radiator is much less for the whole height of the radiator than in the wall coil, where the pipes are placed horizontally, making the wall coil much more effective per square foot of surface. Approximately we can say that a wall coil will do 50 per cent more per square foot than a cast iron radiator. Their extensive use, however, excepting in shop buildings, is always more or less questionable, owing to their unsightly

appearance and the difficulty of installation in many places.

Flue Radiators—Besides the usual radiator in which a large proportion of the heat is given off by radiation and a smaller portion by convection, there is what are known as flue radiators. In a flue radiator each section, as shown in Fig. 14, has a projecting flange at the outer edge, so that there is confined in the radiator itself a series of narrow hot air flues. In these radiators only the external surface of the radiator acts as radiating surface. The interior surfaces of the radiator act as indirect radiators to heat the air which is drawn up from below the radiator. Table XVI gives the loss by radiation from the radiator as separated from the loss due to the heat transmitted to the air in the flues.

TABLE XVI. HEAT LOSS FROM FLUE RADIATORS.

2.	Rated surface. square feet	42
4.	Temperature steam	212
5.	Temperature external air	70
6.	Difference between steam and air	140
7	Condensation per sq. ft. rated surface	.227
8.	B. T. U.'s per deg. diff. per sq. ft. rated surface	1.57
9.	Temperature of air entering flues	70
10.	Temperaure of air leaving flues	152
11.	Cubic feet of air leaving flues per minute	45.77
12.	Average velocity of air leaving, ft. per minute	171.3
13.	Percentage of heat transmitted by flues	45
14.	Percentage of heat radiated	55

The action of the flue radiator depends upon the design of the flues. There should be no point of restricted flue area; that is, the air should be given a free passage from the base of the radiator to the top. Flue radiators are particularly serviceable in rapidly circulating the air in the room and can be used in a large room having small window surfaces to assist in heating the air in the room more rapidly than is done by the ordinary radiator. The flue radiator is also used in connection with ventilation, in which case the base of the radiator is closed and is

connected with the outside air as shown in Fig. 22, page 74. This phase will be taken up more in detail under the head of ventilation.

Heat Lost from Radiators Under Varying Temperatures.—In the foregoing tables it has been assumed

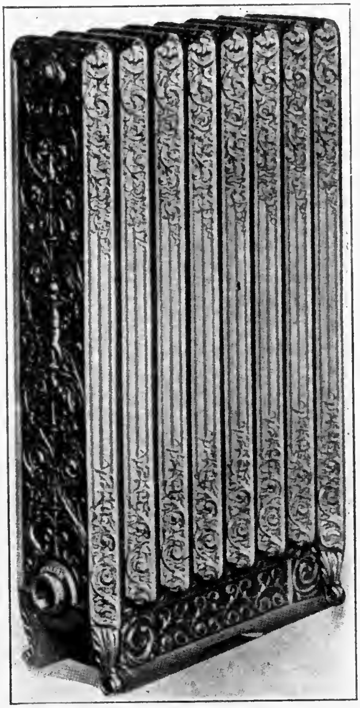


Fig. 14. Cast Iron Flue Radiator.

that the heat lost per degree of difference of temperature between the steam in the radiator and the air outside the radiator was a constant quantity. In general this may be

assumed as true for the ordinary conditions under which radiators operate. Where radiators are operated on very high or very low temperatures there is a difference in the amount of heat transmitted per degree of difference of temperature. Table XVII gives the heat transmitted for each degree difference of temperature between the steam inside and the air outside the radiator per hour per square foot of surface for the two-column cast iron radiator 38 inches high.

TABLE XVII. HEAT TRANSMISSION.

Difference in temperature.	B. t. u. transmitted per deg. diff. per hr.
80	1.425
90	1.455
100	1.485
110	1.515
120	1.55
130	1.59
140	1.635
150	1.665
160	1.71
170	1.745
180	1.77
190	1.815

For ordinary conditions of operation—that is, when the steam is at from 1 to 5 pounds pressure and the temperature of the room is 70 degrees—there will be no necessity to consider this variation in the transmission of heat due to differences of temperature between the steam and the air. There are, however, conditions in drying rooms and similar places that are to be kept at a very high temperature, where this will make an appreciable difference in the amount of radiation to be used. In vacuum systems also, where a very low vacuum is carried, it would be necessary to take these factors into consideration.

Painting may have an appreciable effect upon the heating transmission through a radiator. The effect of painting is entirely a surface effect, as the number of coats of painting on a radiator produce very little differ-

ence. The heat transmission depends upon the last coat put on. A series of experiments carried on recently showed the following relative transmission:

TABLE XVIII. RELATIVE VALUE OF RADIATOR PAINTS.

Kind of Surface.	Relative Transmission.
Bare iron surface	1.
Copper bronze	.76
Aluminum bronze	.752
Snow White Enamel	1.01
No Luster Green Enamel	.956
Terra Cotta Enamel	1.038
Maroon Glass Japan	.997
White Lead Paint	.987
White Zinc Paint	1.01

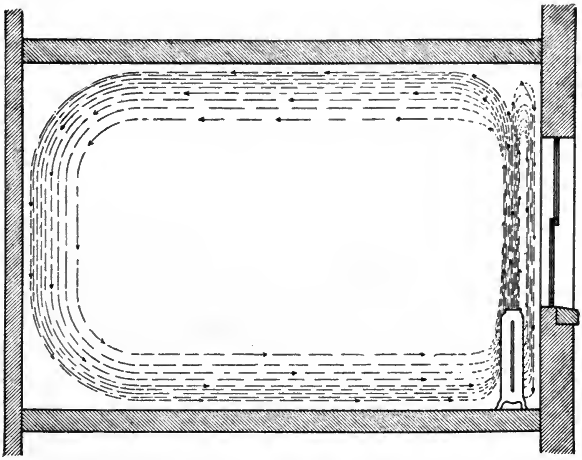


Fig. 15.

Installation of Direct Radiators.—The following suggestions apply to the placing of radiators in the room. *The radiators should be placed in the coldest portion of the room.* In general it is best to place the radiators in

front of the window, selecting a radiator of such height that the top will be an inch or two below the window sill. There are a number of advantages in placing the radiator in front of the window. Probably the most important is the fact that it reduces the strong cold down draft along the window surfaces.

Figure 15 shows the effect upon the circulation of the air by placing the radiator in front of the windows. In this case we get two separate currents of air. The current rising from the radiator divides, one current passing out into the room, being cooled by the wall surfaces and objects in the room, dropping down to the floor and passing back along the floor to the radiator; the other current, passing directly to the cold wall surface, is cooled, drops down along this surface and comes back to the radiator, making the circulation along the cold walls and windows close to the radiator a local one which does not affect the occupants of the room.

Carpets and rugs should not extend under the radiator. If a radiator is allowed to stand upon a carpet or rug for any great length of time, the heat from the legs of the radiator will eventually deteriorate the fabric of the rug. In a carpeted room the radiator may be placed upon a hardwood or a marble base.

When radiators are placed next the wall a space of 1½ inches at least should be left for the circulation of air behind the radiator.

Unless otherwise specified, radiators are usually tapped as in Table XIX.

TABLE XIX.—RADIATOR TAPPINGS.

For one-pipe work radiators containing—	Inches.
24 sq. ft. and under	1
From 24 to 40 sq. ft.	1¼

From 40 to 100 sq. ft....................................1½
Above 100 sq. ft..2

For two-pipe work radiators containing—

48 sq. ft. and under....................................1x¾
From 48 to 96 sq. ft....................................1¼x1
Above 96 sq. ft...1½x1¼

Rules for Direct Heating.—The best method of figuring radiating surface is to determine the actual heat loss from the room in B. t. u., for the form of radiator which you propose to use. Suppose, for example, that a two-column cast iron radiator is selected. The steam pressure to be carried is 5 pounds. The temperature in the room is required to be 70 degrees. Referring to the table of heat losses from direct radiators (Table XV), we see that a two-column cast iron radiator loses 1.65 heat units per degree difference of temperature per square foot of rated surface per hour. The temperature corresponding to 5 pounds pressue of steam as given in Steam Table (Table VI), is 227 degrees, and the difference between this and the temperature of the room will be 157 degrees. Then the heat lost will be $1.65 \times 157 = 259$ heat units per square foot per hour. Dividing the heat loss as given by the rule for loss of heat, by 259 gives the number of square feet of radiation to be used.

This is the only method that can be used at all in rooms where conditions are exceptional. For rooms of ordinary construction, heated to 70 degrees, and an outside temperature of 0°, a large number of thumb rules are used. Some of these thumb rules are as follows:

In the following rules the expression wall surface means exposed wall surface, that is, those surfaces which have outside air temperature on one side and room temperature on the other side.

RULE 1. *Divide the volume of the room by* 55. *Add*

one-fourth of the exposed wall surface; add the glass surface, and multiply the sum of these three quantities by .28. The product will be the direct radiation in square feet.

RULE 2.—*For ordinary rooms. Divide the exterior wall surface by 4, add the glass surface and multiply the sum by .4.*

B.—For entrance halls. Divide the exterior wall surface by 4, add the glass surface and multiply the sum by .54.

C.—For the wall surface in basement rooms below the ground line. Divide the wall surface by 4 and multiply the result by .17.

D.—For floors having unheated space below. Divide the floor space by 4 and multiply the result by .23.

RULE 3. *Divide the volume of the room in cubic feet by the factors given below and the quotient will be the radiating surface in square feet.*

First floor rooms, two sides exposed:........	50
First floor rooms, three sides expose........	45
Sleeping rooms, second floor................	60 *to* 70
Halls and bath rooms........................	50
First floor rooms, one side exposed.........	55
Offices	50 *to* 75
Factories and stores........................	75 *to* 150
Assembly halls and churches.................	75 *to* 150

RULE 4. (BALDWIN'S RULE).—*Divide the differences between the temperature at which the room is to be kept and that of the coldest outside temperature by the difference between the temperature of the steam in the radiator and that at which you wish to keep the room and the quotient will be the square feet of radiating surface to be allowed for each square foot of equivalent glass surface.*

By equivalent glass surface is meant the wall surface divided by 4 plus the glass surface.

In all of these rules the factors to be allowed for exposure should be applied. These factors are given under the head of "Factors for Exposure." Where the rule does not involve the contents of the room it will be necessary in very large rooms or in rooms where the wall surface is very small in proportion to the contents of the room, to add a certain proportion of radiation, usually not more than 20 per cent, to allow for heating the air in the room quickly when it has once been allowed to cool.

Example (Direct Radiation).—In order to understand better the methods of determining the heating surface required for a given house, it would be best to consider a concrete example. Figs. 16, 17 and 18 represent the basement, first and second floors of a residence. The house is constructed of wood, sheathed, papered and clap-boarded on the outside and plastered on the inside. On the first floor the rooms are 9 feet 6 inches high and on the second floor 8 feet 6 inches high. The windows are 6 feet high and the standard size is 3 feet wide. Table XX gives the general dimensions of the room and the heat losses from the various rooms, assuming the temperature of the outside air to be zero and the temperature of the inside to be 70 degrees.

TABLE XX.—DIMENSIONS AND HEAT LOSSES.

Room.	Dimensions.	Volume.	Wall Surface.	Window Surface.	B.t.u. Lost Per Hour.
Parlor	13'9"x12'9"x9'6"	1,665	216	36	9,450
Sitting room	14'3"x15'6"x9'6"	2,100	95	48	7,035
Dining room	12'6"x13'9"x9'6"	1,640	145	36	7,350
Kitchen	13'0"x13'0"x9'6"	1,610	249	36	10,300
Hall	12'9"x10'0"x9'6"	1,210	197	18	7,035
Second Floor.					
W. chamber	11'6"x13'6"x8'6"	1,320	172	48	10,050

Alcove	10'0"x 9'6"x8'6"	810	130	40	7,560
So. chamber.....	12'6"x14'9"x8'6"	1,560	172	24	7,035
N. chamber......	13' x13' x8'6"	1,440	188	24	7,455
Bath	6' x 8' x8'6"	410	50	18	3,150
E. chamber......	13' x 8' x8'6"	880	160	18	5,250
Front hall.......	14' x 4' x8'6"	885	33	18	2,730
	8' x 6' x8'6"				

TABLE XXI.—RESULTS OF COMPUTATION, DIRECT SYSTEM.

	B.t.u. from Table XXI.	B.t.u. Corrected for for Exposure.	Radiating Surface. Two Column Cast Iron Sq. Ft.	Radiating Surface by Rule 3.
First Floor.				
Parlor	9,450	10,395	39	33.5
Sitting room..	7,035	7,035	27	38
Dining room...	7,350	8,085	30	30
Kitchen	10,300	10,300	39	32
Hall	7,035	7,770	29	24
Second Floor.				
W. chamber...	10,050	11,055	42	22
Alcove	7,560	8,316	31	13
S. chamber....	7,035	7,035	27	26
N. chamber....	7,455	8,190	31	24
Bath	3,150	3,465	13	7
E. chamber...	5,250	5,250	20	14.7
Halls	2,730	3,003	12	14.7

The method used in determining the British thermal units lost from the room is as follows: In Table XII a wall constructed as described loses .25, Table XI gives the loss from the glass surfaces as 1.03. Then multiplying the wall surface by .25 will give the B. t. u. lost per square foot per degree difference and each square foot of glass surface loses about one B. t. u. per square foot. Take, for example, the parlor. The wall surface is 216 square feet. Multiply this by .25; the result, 54 B. t. u. lost per square foot per degree difference of temperature. Add the loss from the glass surface, 36 B. t. u., makes a total loss of 90 B. t. u. Multiplying this by the difference between the outside and the inside temperature, gives the heat lost, or $90\times70=6,300$ B. t. u. lost from the room per hour. To this must be added the loss through the wall by leakage which has been assumed to be 50 per cent, making the total loss 9,450 B. t. u.

In Table XXI the second column gives the B. t. u.

as determined in Table XX; the third column the B. t. u. corrected for exposure, 10 per cent being added to rooms having north and west exposures, as, in this case, the prevailing winds are from the west. Column 4 gives

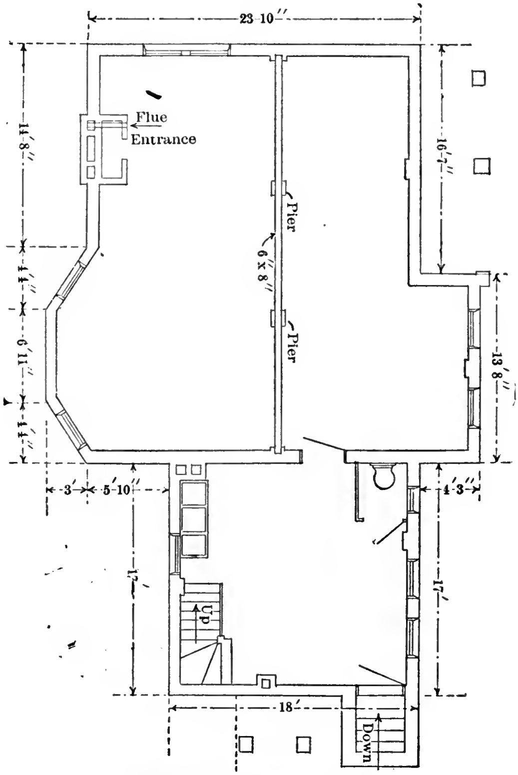


Fig. 16. Basement. Plan.

the radiating surface required to heat the rooms with a two-column cast iron radiator. Column 5 gives the radiating surface as determined by Rule 3.

The quantities in column 4 are obtained in the following manner. The steam pressure to be carried in the radiator is 5 pounds. The corresponding temperature

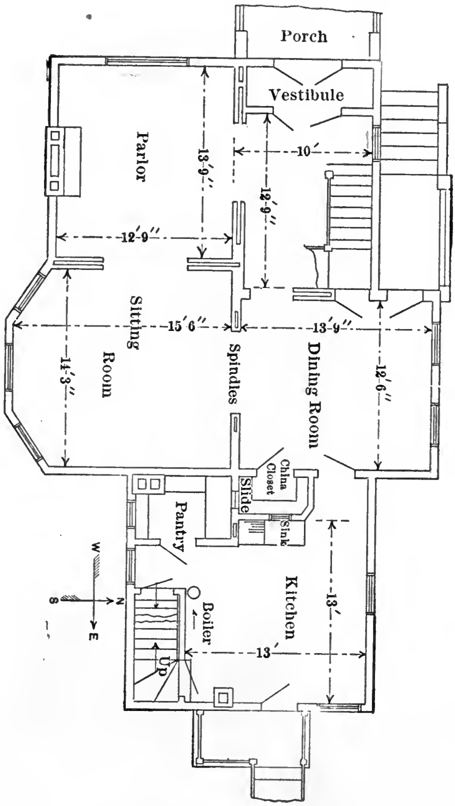


Fig. 17. First Floor.

of steam is 227 degrees. The temperature of the room is 70 degrees. The difference in temperature between the room and the steam will be 157 degrees. In the last

column of Table VII the heat lost for a two-column cast iron radiator is given as 1.65 B. t. u. per degree difference per hour. Then the total heat lost per square foot per hour will be $157\times1.65=260$ B. t. u., that is, each square foot of radiator surface will give to the room

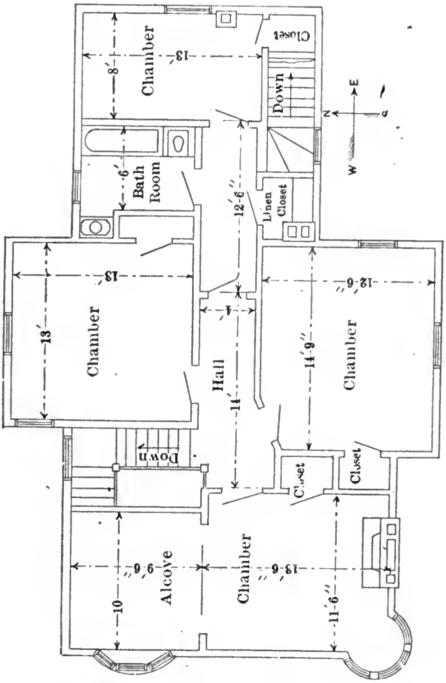


Fig. 18. Second Floor.

260 heat units per hour. Dividing the heat lost from the room, as given in column 3, by 260, will give the results shown in column 4.

In column 5 the radiating surface has been determined by Rule 3, which is sometimes called the Volume

Rule; that is, the cubic contents of the rooms are divided by a certain factor, depending upon the location of the room. A careful comparison of columns 4 and 5, together with an inspection of the plans, will show the inconsistency of the volume rule. The volume rule can be used only where the room has an average amount of cubic contents, as compared with its wall surface. To get the best results it is better to employ the method that has been used in determining the results in column 4.

The case often arising where a contractor guarantees to heat a building to 70° when the outside temperature is zero. When the plant is finished the temperature outside is many degrees above zero. What temperature should the rooms heat to under this higher outside temperature in order to have the room heat to 70° in zero weather?

Assume t_1=temperature of the outside air from contract conditions usually 0°.

t_2=temperature of air in the room which was guaranteed by contractor.

t_3=temperature of steam in the radiator during test.

t_4=actual temperature outside air during test.

t_5=computed temperature of room for test conditions.

The heat loss from the room under contract conditions is

$$\left(\frac{W}{4}+G\right) n(t_2-t_1) \tag{1}$$

Heat loss from room under test conditions is

$$\left(\frac{W}{4}+G\right) n(t_5-t_4) \tag{2}$$

Heat loss from radiator under contract conditions =

$$(t_3—t_2)c \qquad (3)$$

where c is coefficient of transmission. Heat loss from radiator under test conditions =

$$(t_3—t_5)c \qquad (4)$$

Then equation (1) must equal (3) and equation (2) must equal (4), hence

$$\left(\frac{W}{4}+G\right)n=\frac{(t_3—t_2)c}{t_2—t_1} \text{ and} \qquad (5)$$

$$\left(\frac{W}{4}+G\right)n=\frac{(t_3—_5)c}{t_5—t_4} \qquad (6)$$

Equating the right-hand member of equations (5) and (6) we have

$$\frac{t_3—t_2}{t_2—t_1}=\frac{t_3—t_5}{t_5—t_4} \qquad (7)$$

Assuming $t_1=0°$ and $t_2=70°$ and solving for t_5

$$t_5=.695t_4+70° \qquad (8)$$

The following Table XXII has been computed from equation 8 and shows the room temperature for different outside temperature with the same radiation in the room and the same steam temperature.

TABLE XXII.

Room Temperature Corresponding to Temperature of Outside Air.

Temperature of outside air.	Temperature of room 2-column radiator.	Temperature of room 3 column radiator.
—30	52	53
—20	58	59
—10	64	64
0	70	70
10	77.5	75
20	83	83
30	90	89
40	97	95
50	103.5	105.5
60	110	108
70	117	115
80	123.5	121.5
90	130	128
100	137	134.5

Table XXII shows the temperature that should be obtained in a room for various outside temperatures, the original guarantee being to heat the house to 70 degrees in zero weather.

Transmission of Heat Under Various Conditions.—The German engineers use the following method of calculating the amount of heat which will pass through a square foot of heating surface per hour. Assume H to be the total heat transmitted per hour; t the difference between the average temperature of the hot and cold fluids; c a constant depending upon the kind of surface, the hot fluid and the cold fluid and let a equal the area of the surface. Then

$$H = c\ t\ a.$$

Rietschel gives the following values for the heat transmitted:

	c
From air or smoke through a clay plate about ⅜ inch thick to air	1.00
From air or smoke through a cast or sheet iron plate to air	1.4 to 2.0
From air or smoke through a cast or sheet iron plate to water or the opposite	2.6 to 4.0
From steam through cast iron or wrought iron plate to air	2.2 to 3.6
From steam through a metal wall to water	160.0 to 200.0

CHAPTER IV.

Design of Indirect Steam Heating System.—It is seldom that indirect radiators only are installed. This is due chiefly to the increased cost of installation and operation of such a plant, as compared with a plant using both direct and indirect radiation. In a residence heated by indirect radiation alone, it will be necessary to introduce an excess of air over that required by ventilation. This materially increases the cost of operation. In designing an indirect heating plant the loss of heat from the building is figured in the same way as with the direct system. In using indirect radiation alone it will be necessary to introduce enough air so that the heat left in the room will be sufficient to take care of the losses from the walls and windows. In order to determine the amount of surface to be placed in the room, it is necessary to know the temperature to which the radiator will heat the air and the amount of heat given off by the indirect radiator under different conditions of operation.

Heat Lost from Indirect Steam Radiators.—The amount of heat that may be obtained from a given indirect radiator will depend upon the temperature at which the air is taken in, the temperature of the radiator, and the cubic feet of air passing through the radiator. The following table gives the relation between the above quantities, assuming the temperature of the air entering the radiator to be zero, the temperature of the steam in the radiator 227 degrees, the temperature corresponding to 5 pounds gauge pressue:

In school buildings and in buildings where the flues

are of ample size the amount of air passing per square foot of radiating surface may be assumed to be 200 cubic feet per hour. In residences and buildings where the flues are usually small, the amount of air passing

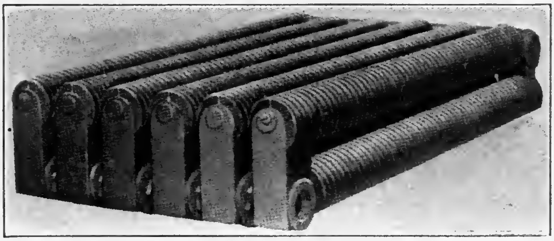


Fig. 19. Extended Surface Indirect Radiator.

per square foot of surface per hour does not exceed 150 cubic feet.

From the results of the tests on indirect radiators given, the following points may be noted:

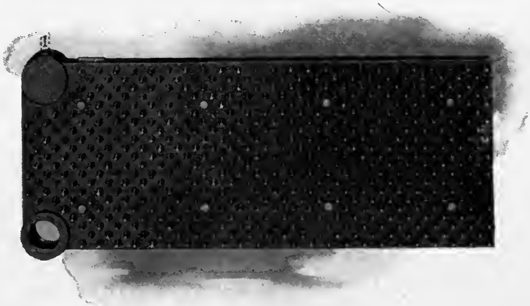


Fig. 20. Long Pin Indirect Radiator.

If the temperature of the air entering the radiator is constant, then the temperature of the air leaving

the radiator will decrease as the amount of air passing through the radiator is increased.

In order to determine the amount of heat transmitted by the radiator it is necessary to assume the number of cubic feet of air that will pass through the radiator per square foot of radiation. You will also note the difference between the extended surface radiator and the long pin radiator (Fig. 20). As shown in Table XXIII, the temperature at which the air is heated by the long pin is less than the temperature to which the air is heated by the short pin with the same quantity of air passing. This is undoubtedly due to the fact that the pins are so long

TABLE XXIII. HEAT LOSSES FROM INDIRECT RADIATORS.

Cubic feet of air passing per sq. ft. of radiation.	Increase in temperature of the air passing the radiator.		Pounds of steam condensed per sq. ft. of radiation.		B. t. u. transmitted per sq. ft. of radiation per degree diff. in temper. of air passing through radiator and the steam.	
	Standard Pin.	Long Pin.	Standard Pin.	Long Pin.	Standard Pin.	Long Pin.
50..........	147	140	.125	.15	.80	.95
75..........	143	137	.17	.21	1.17	1.27
100..........	140	135	.24	.26	1.51	1.60
125..........	138	132	.295	.31	1.85	1.90
150..........	135	129	.355	.36	2.22	2.20
175..........	132	126	.41	.405	2.57	2.47
200..........	130	123	.47	.45	2.90	2.72
225..........	127	120	.53	.49	3.25	3.00
250..........	123	118	.585	.53	3.60	3.20
275..........	121	115	.645	.57	3.90	3.40
300..........	119	112	.700	.61	4.22	3.60

that the ends become cooled. On the other hand, the long pin type is a very desirable type to use when one wishes to pass large quantities of air, as the radiator has ample air passage. This is primarily the work for which it is designed. The short pin gives better results for ordinary houses where small quantities of air pass through the radiator.

Installation of Indirect Radiators.—Indirect radiators are placed in a chamber or box, usually situated in the basement of the building, as close as possible to the vertical flue leading to the room which they are to heat. The air is admitted to the radiator by a duct or flue, connected with the outside air. This duct should be supplied with a suitable damper and, if possible, be so arranged as to close automatically when the steam pressure is taken off the radiator. The cold air is usually admitted directly beneath the radiator and the heated air on leaving the room is taken off at one side.

TABLE XXIV. INDIRECT RADIATORS—TEMPERATURES OF LEAVING AIR.

Temperature of air entering the radiator.	Temperature of air leaving the radiator with a velocity of 200 cu. ft. of air per sq. ft. surface. Standard Pin	Long Pin	Temperature of air leaving the radiator with a velocity of 150 cu. ft. of air per sq. ft. surface. Standard Pin	Long Pin
0	130	125	135	128
10	134	128	139	132
20	139	132	144	136
30	144	136	149	140
40	148	141	153	144
50	153	144	158	146

The casing surrounding indirect radiators is usually built of galvanized iron and it should be bolted together with stove bolts, so that the casing may be easily removed. A much better method, but one which is more expensive, is to enclose the radiator in a small brick chamber with cement floor. This chamber should be large enough so that the radiator is accessible for repairs. Sometimes a duct is provided in the radiator casing so that cold air may be taken around the radiator and mixed with the heated air through a suitable damper, controlled from the room which is heated. This is a very common ar-

rangement in school buildings. Fig. 21 shows a sketch of an arrangement of this kind.

The pipes or ducts leading from an indirect radi-

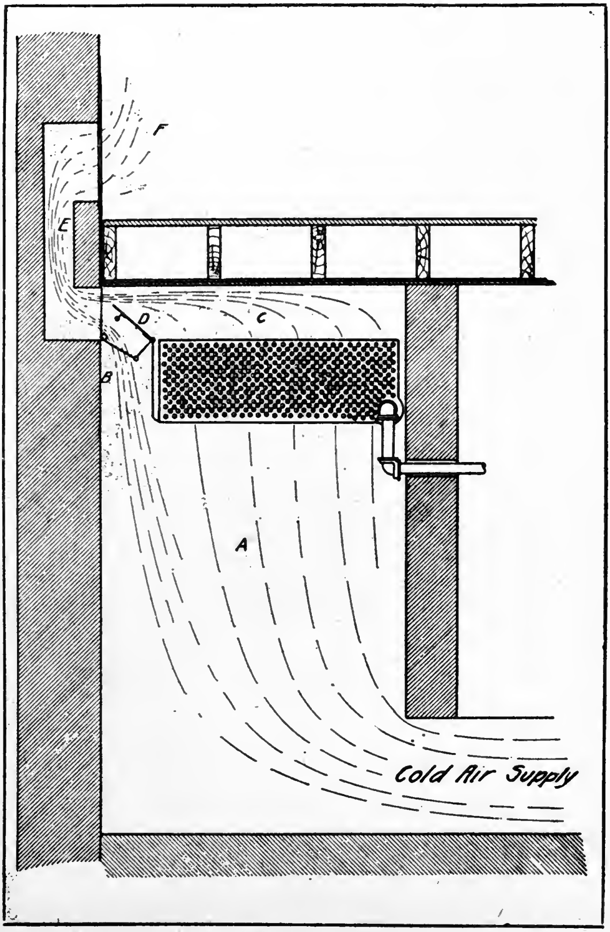


Fig. 21.

ator should be carried to the room as directly as possible. It is better to have a long cold air pipe than a short hot air pipe. A long horizontal hot air pipe should be avoided. Where the air from the indirect radiator is to be used primarily for ventilation it is best to place the hot air register near the ceiling.

The indirect radiators are usually suspended in the radiator chamber on iron pipes supported by rods hanging from the ceiling. There should be at least 10 inches clear space between the radiator and the bottom and top of the casing. The casing of the radiator should fit the radiator as closely as possible, so that very little air is allowed to pass around the radiator without being heated. Indirect radiators should be placed at least 2 feet above the water line of the boiler, if they are to be operated on a gravity system of circulation, and should be so arranged that the condensed water will drain from them without trapping. The tappings of these radiators are the same as for double pipe direct steam radiators. The following table gives the general proportions for an indirect radiator system:

TABLE XXV.—SIZE OF FLUES FOR INDIRECT RADIATOR.

Heating Surface, Sq. Ft.	Area of Cold Air Supply, Sq. In.	Area of Hot Air Supply, Sq. In.	Size of Brick Flue for Hot Air.	Size of Register.
20	30	40	8x 8	8x 8
30	45	60	8x12	8x12
40	60	80	8x12	10x12
50	75	100	12x12	10x15
60	90	120	12x12	12x15
80	120	160	12x16	14x18 ~~252~~
100	150	200	12x20 = 240	16x20 320
120	180	240	14x20	16x24
140	210	280	16x20	20x24

Heating Effect of an Indirect Radiator.—It is usual to assume that the air enters the radiator at zero

degree of temperature, in which case it will leave the radiator at about 130 degrees, the steam pressure in the radiator being 5 pounds and the velocity through the radiator being 200 cubic feet per hour per square foot of radiator. Under the above conditions an ordinary pin radiator will give off 470 B. t. u. per square foot, or, say approximately, 450 B. t. u. Under these conditions the air entering the room will be at a temperature of 130 degrees, and if the temperature of the room is 70 degrees this air will be capable of losing to the room 60 degrees, or, in other words, there is 60 degrees of temperature available in this air for heating purposes, or of 450 B. t. u. given out by the radiator 210 B. t. u. are available for heating the room.

SOME RULES FOR INDIRECT HEATING.

RULE 1.—*For ordinary rooms. Divide the wall surface by 4, add the glass surface, and multiply the sum by .6. The quotient will be the amount of indirect radiation necessary to heat the room.*

B.—*For entrance halls. Divide the exterior wall surface by 4, add the glass surface and multiply the sum by .75, the product will be the number of square feet of indirect radiation.*

RULE 2.—*Figure the heating surface the same as for direct heating. Add 40 per cent.*

RULE 3.—*Divide the volume of the room by 40. The quotient is the square feet of indirect surface required to heat the rooms on the first floor. For second and third floor rooms divide by 50, and in stores and large rooms divide by 60.*

Example of Indirect Heating.—Take the same house

that was used in the problem for direct heating. In this case all rooms are to be heated by indirect radiation. It is in actual practice an unusual arrangement, but it is figured out in this way as an illustration merely.

The heat loss in this house will, of course, be the same in both direct and indirect heating and is given in Table XXI (p. 58). Assume that the air enters the radiator at zero degrees and leaves at 130 degrees; that the steam in the radiator is at 5 pounds pressure and that 200 cubic feet of air is passed through the radiator per square foot of surface. From the results determined in paragraph headed "Heating Effect of the Indirect Radiator" each square foot of radiation gives approximately 450 B. t. u. If the temperature of the room is 70 degrees only 60 degrees of the heat given to the air is effective in heating the room. As the total amount of increase in temperature is 130 degrees, only approximately 60÷130, or 45 per cent, is available for heating. Each square foot of indirect radiation gives off .450 B. t. u., 45 per cent of 450, or 200 B. t. u., will be available for heating the room. The heat loss as given in the table for the parlor is 10,395 B. t. u. Dividing this by 200 gives 52, the number of square feet of radiation required for the room.

TABLE XXVI.—RESULTS OF COMPUTATION, INDIRECT SYSTEM.

	B. t. u. Lost Per Hour.	Size of Radiator in. Sq. Ft.	Area Hot Air Flue.	Area Vent Flue.	Volume of Room.
First Floor—					
Parlor	10,395	50	100	12x12	900
Sitting room	7,035	35	70	8x12	700
Dining room	8,085	40	80	8x12	720
Kitchen	10,300	50	100	12x12	1,000
Hall, 2d floor	15,800	73	145	12x12	1,500
Second Floor—					
W. chamber, alcove	19,370	93	180	12x20	1,600
So. chamber	7,035	35	70	8x12	700
N. chamber	8,190	40	80	8x12	750
Bath	3,465	17	40	6x 8	300
E. chamber	5,250	24	50	6x 8	500

Size of Hot Air Pipe.—Fifty-two square feet of radiation passing 240 cubic feet of air per square foot will pass 12,480 cubic feet of air per hour; 12,480 is 3.47 cubic feet per second. Allowing a velocity of 5 feet per second, the area of the hot air pipe is $3.47 \div 5 = .69$ square feet. This equals 99 square inches, which is the proper area of the pipe. The size of the cold air pipe leading to the radiator is usually made the same size of the hot air pipe. Table XXVI gives the results for the whole house computed in the same manner as given above. In the table the odd figures and decimals have been left off.

In selecting the size of radiator for a room, it is necessary to select those that vary by 10 square feet or more, as indirect radiator sections are not made smaller than 10 square feet per section. In a house where the radiators would be less than three sections, it is necessary to put two or three rooms on the same radiator, as it is not desirable to make very small indirect stacks. There is always danger, however, in taking the heat for two separate rooms off the same radiator, that the heat will not distribute equally between the two rooms. When separate rooms are heated from the same radiator, care should be taken to see that pipes leading to the two rooms have about the same length and as nearly as possible the same resistance.

Combination of Direct and Indirect.—A much more common arrangement of indirect radiators is to put in just enough indirect radiation to give the proper amount of air for ventilation and supply the additional heat for the room with direct radiation. Each system is installed as though the two were separate, except that they take

their steam from the same steam mains and return into the same return pipes. In this system the direct radiators can be installed on the one-pipe system, but the indirect should be installed on the two-pipe system, as indirect radiation does not work well on a one-pipe system.

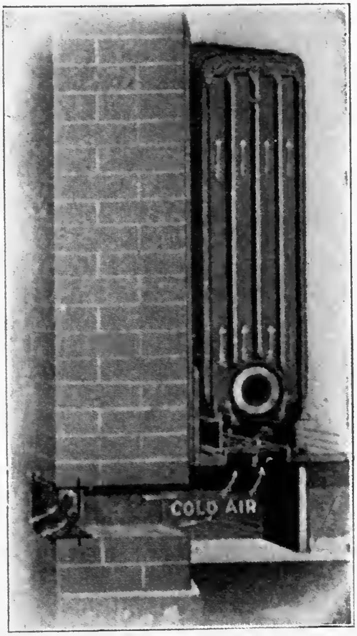


Fig. 22. Arrangement of Flue Radiator.

It is not necessary to put indirect radiation into all the rooms of a residence. They are put into the princpial living rooms, the hall and the large bedrooms. Where the house is small it may be necessary to put indirect radiation only in the sitting room and in the hall. An ex-

ample of this kind will be taken up under the head of ventilation.

Flue Radiators.—Where only a small quantity of air is needed for ventilation flue radiators may be used in place of indirect radiators as shown in figure 22.

The damper in the outside wall regulates the amount of air passing into the room and in extremely cold weather this may be entirely closed. Table XVI on page 50 shows the heat loss from this type of radiation and the amount of air that the flues will pass. In figuring this type of radiation figure the same as for direct radiation and add 25%. Each 30 square feet of flue radiation will furnish ventilation sufficient for one person.

CHAPTER V.

STEAM BOILERS.

Types.—Boilers are divided into two general classes—fire tube or tubular, and water tube or tubulous boilers. The commonest form of boiler used for heating purposes in this country is what is known as the return flue fire tube boiler. These boilers are adapted to plants of over 30 and under 150 horsepower and where the pressure does not exceed 100 pounds. For pressures above 100 pounds it is customary to use water tube boilers. There is one exception, that is the Scotch marine boiler, which is a fire tube boiler and which can be made to withstand pressures of 200 pounds and over in large sizes, as in this boiler the fire does not come in contact with the outside shell.

For heating purposes there have been introduced a number of special forms of boiler, a great many of these forms being built of cast iron. Cast iron boilers are not usually operated at pressures exceeding 10 pounds.

Any of these forms of boilers may be used for heating, the selection and the proper form will depend upon the conditions in each particular case. In selecting a boiler the following points should be taken into consideration: The boiler must be of sufficient strength to withstand the maximum pressure to be carried. This does not usually exceed 10 pounds. It must have sufficient heating surface in proportion to the grate surface to be economical. The stack temperature in a low pressure boiler should not exceed 500 degrees. The boiler must have sufficient liberating surface so that the steam formed in the water may escape from the surface of the

water, without carrying a large quantity of water with it. The boiler must have large circulating areas so that the water may be circulated freely to the heating surfaces and the steam formed may pass away from the heating surfaces without restrictions. The steam that forms on the heating surfaces rises in bubbles and is liberated from the surface of the water. If the boiler has insufficient liberating surfaces or the circulating areas are contracted the steam cannot rise rapidly enough and bubbles of steam remain on the heated surfaces. These bubbles prevent the water from reaching the heating surfaces and as steam is a poor conductor of heat this results in an overheating of these surfaces. This trouble may be very serious, especially in the water tube type of boiler, and results in the burning out of the tubes. In cast iron boilers the lack of proper liberating surfaces and sufficient steam space often causes excessive priming. The question of circulating area and liberating surface is of more importance in a low pressure boiler plant than in a high pressure plant, as steam at 5 pounds pressure has about six times the volume of steam at 100 pounds pressure; so that to have relatively the same circulating area and liberating surface in a low pressure boiler, we should have five times as much as in a high pressure boiler.

In boilers for heating purposes it is desirable that they should have sufficient steam space, and a large storage of water, particularly if the plant is to be continuously operated. In boilers having large water storage it is possible to maintain a steam pressure on the boiler all night under banked fires. Where boilers are to be operated only occasionally, it may be desirable to have a small quantity of water, as each time the boiler is started it is necessary to heat all the water in the boiler before steam is

formed. The ordinary fire tube return flue boiler, on account of its large water storage, liberal circulating areas and large liberating surface, is a desirable one for heating purposes in large buildings.

Proportion of Boilers.—The heating surfaces in a boiler are those surfaces which have water on one side and hot gases on the other. A boiler should be so proportioned as to transmit as much of the heat generated by the fuel to the water as possible. Experience has determined that for best results in boilers of 50 horsepower and over a square foot of heating surface should evaporate not more than three pounds of water per square foot of heating surface. For small houses, where heating boilers of but a few horsepower are used, it is not usual to allow a square foot of heating surface to evaporate more than 2 pounds of water and when a square foot of heating surface evaporates more than the amounts given above, the transmission of heat through the plate becomes so rapid that all the heat is not removed; the result is an excessively high stack temperature and a corresponding loss of heat. Surfaces that have steam on one side and hot gases on the other are called superheating surfaces. It is not advisable to have superheating surfaces in a boiler.

Small heating boilers are distinctly different from power boiler or heating for large plant. In large plants coal is being fed to the boiler almost continuously and the flues are carrying a large quantity of gases. Small house heating boilers are fed at infrequent intervals and the flues of these boilers do very little of the work of transmitting heat. In small boilers a distinction must be made between the flue surface and the fire surface. The fire surfaces are those

heating surfaces upon which the rays of radiant heat from the fire impinge directly. During the periods when the drafts are closed most of the steaming in the boiler is produced by the fire surface, it is therefore important in a house heating boiler to have a large amount of fire surface as compared with the flue surface. It is good practice to have 60 per cent fire surface and 40 per cent flue surface in cast-iron house heating boilers.

The proportion of grate surface to heating surface depends upon the kind of fuel and the intensity of the draft. In small boilers used for heating purposes it is usual to allow one square foot of grate surface to every 15 to 30 square feet of heating surface. For boilers 50 horsepower and over it is usual to allow from 30 to 40 square feet of heating surface per square foot of grate surface and in very large boilers the ratio is 50 to 60 square feet of heating surface per square foot of grate.

The rate of combustion for anthracite coal will vary from 2 to 6 pounds of coal per square foot of grate surface per hour with average draft. With bituminous coal under similar circumstances, 3 to 8 pounds will be burned in the smaller boilers and 8 to 15 pounds in the larger sizes.

The air opening to be allowed in the grates depends upon the kind of coal, but usually does not exceed 50 per cent of the area of the grate. Anthracite and the better grades of bituminous coal do not require as large opening as do the slack coals.

The term boiler horsepower as applied to boilers has no definite value and varies with local customs, and the opinion of the manufacturer.

Boiler Horsepower.—The rating of a boiler should be the amount of steam it can evaporate with good economy and without producing wet steam. In purchasing a boiler specify the number of square feet of grate surface the boiler should contain. This is a better criterion of the work that the boiler will do than the horsepower rating. The American Society of Mechanical Engineers has adopted the following rating for the horsepower of a boiler:

A boiler horsepower is 34½ pounds of water evaporated from feed water at 212 degrees, to steam at 212 degrees, which is called the from and at evaporation. According to this rule, if three pounds of water are evaporated per square foot of heating surface, we would allow from 10 to 12 square feet of heating surface for each boiler horsepower.

The American Society of Heating and Ventilating Engineering recommended the following ratings for cast-iron house-heating boilers:

TABLE XXVII.

Rating of House-Heating Boilers.

Area of Grate. Sq. Ft.	Coal Burned per Hour per sq. ft. of Grate. Lbs.	Total Coal Burned per Hour. Lbs.	Rating of Boiler.
1	2.67	2.67	82
1.5	2.96	4.44	140
2	3.59	7.18	226
3	4.21	12.63	390
4	4.55	18.20	585
5	4.88	24.40	780
6	5.06	30.36	975
7	5.24	36.68	1,165
8	5.36	42.88	1,405
9	5.48	49.32	1,650
10	5.60	56.00	1,890
11	5.71	62.81	2,125
12	5.82	69.84	2,360
13	5.93	77.09	2,595
14	6.08	85.12	2,915
15	6.23	93.45	3,235
16	6.35	101.60	3,485
17	6.46	109.82	3,730
18	6.51	117.18	4,010
19	6.55	124.45	4,285
20	6.58	131.60	4,545
21	6.61	138.81	4,800

In compiling the table it is assumed—

1. That the area of the grate shall be the area of the opening in which the grate is placed, measured to the outermost limits of air openings.

2. That the boiler is to be used under average working conditions, carrying steam at 2 pounds pressure; that the draft shall be sufficient to burn the number of pounds of coal per hour given in the table, and that the coal used shall be a good quality of anthracite coal having a heating power of 13,000 B. t. u. per pound of dry coal.

3. That the rating as given in the table means the number of square feet of direct radiation steam surface that can be carried by the boiler, based upon the supposition that each square foot of direct radiation steam surface emits 250 B. t. u. per hour with steam at two pounds pressure in the radiator and with air surrounding the radiator at a temperature of 70 degrees.

CHAPTER VI.

STEAM PIPING.

In designing a system of steam piping the three following considerations are the most important: First, that the piping shall be so arranged that all condensed water shall drain from it; second, that it shall be free to expand, that is, so arranged that the joints shall not be strained when the piping is heated; third, that all points in the piping at which air would accumulate shall be provided with some means of removing the air.

In this text the different parts of the piping system referred to will have the following meaning:

MAINS.—Mains are those pipes which lead from the boiler or boiler header to the submains or risers. Usually there are no radiators tapped from these mains.

RISERS.—Risers start from the mains in the basement or attic, and extend up or down through the building. From the risers the connections to the individual radiators are taken.

RETURNS.—All piping carrying condensed water from the steam mains to the boiler is included in the return system. The terms return riser, return main, etc., have the same significance as in the steam system.

RELIEFS OR DRIPS.—A small pipe connecting the steam to the return system so as to carry condensed water to the returns is called a relief or drip. Drips are used at all points where water would collect in the steam system. These drips are sometimes made of large pipe and called equalizing pipes, serving to equalize the pressure between steam and return mains in gravity return systems.

PITCH.—The pitch of a pipe refers to its inclination from the horizontal pipe lines. It is best that pipes should pitch with the current of the steam, so that the steam will assist in the removal of the condensation. Return pipes are usually pitched toward the boiler so that the system may be drained at that point.

WATER LINE.—The water line is the height at which the water stands in the return pipes. In a well designed gravity system it is seldom more than twelve inches above the water line of the boiler.

SIPHON.—When a vertical bend is made in the return main so that the return dips down and returns to its former level, it is called a siphon. All siphons should be provided with a drain (or pet cock).

DAMS.—Sometimes the water level in the boiler is lower than that desired in the piping system and an inverted siphon is placed in the return pipe. No return will then take place until the water has reached the highest point of this bend in the return. A dam should be provided with an air cock.

WATER SEAL.—Where a return pipe enters the return main below the water line it is said to be sealed. It is customary to seal all main riser drips and returns from indirect radiators and pipe coils.

WATER HAMMER.—The rattling and the hammering often heard in pipes is called water hammer. It is caused by steam coming in contact with water or surface in the pipes which is colder than itself. A sudden condensation results and a vacuum is produced into which the water rushes. The blow is often so severe as to crack the fittings and spring the valves. It is most apt to occur when the plant is first started. Accidents from this cause may be avoided by admitting the steam very slow-

ly at first and draining low points in the piping system.

Steam Traps.—Steam traps are vessels usually placed between the steam and the return system to allow the water of condensation to be carried to the return system without steam entering the returns. By the use of

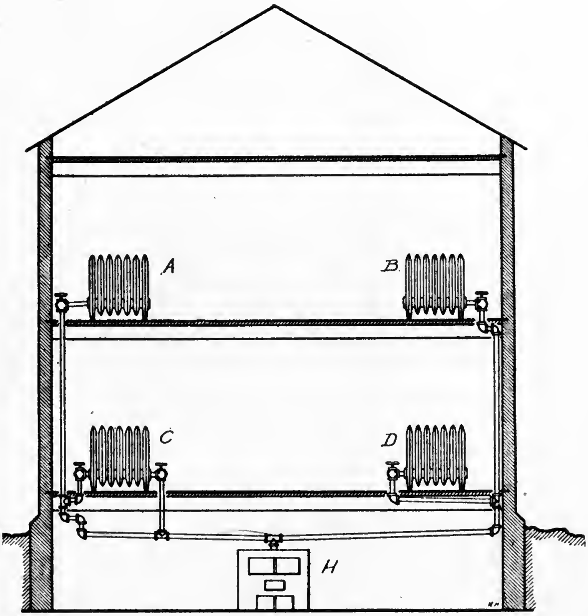


Fig. 23.

steam traps the steam and return mains may have a wide difference of pressure. Steam traps are objectionable as they are liable to get out of order and require frequent repairs.

Systems of Piping.—The systems of piping may be grouped under three general heads. First, the one-

pipe system. In this system the pipe carrying the steam to the radiator also returns the condensed water from the radiator to the boiler. Second, two-pipe system, in which one set of pipes is used to carry the steam to the radiator and an entirely separate set of pipes is used to carry the return water to the boiler. Third, a combination of these two systems. The usual arrangement in the combination system is to run the mains on a two-pipe system, but the connection between the mains and the radiators is on the single pipe system. The one-pipe system has certain fundamental advantages over the two-pipe system. In the one-pipe system the steam and condensed water are always at the same temperature and as a result there is very little opportunity for water hammer. In the two-pipe system the steam and water being separate the water may become considerably cooled below the temperature of the steam, and if at any point in the system it again comes in contact with the water we have condensation of the steam, vacuum forms, causing water hammer. In large plants, however, the one-pipe system is not desirable, as it necessitates carrying a very large quantity of water in the steam mains.

One-Pipe System.—The simplest of all piping systems used in steam heating is what is known as the one-pipe gravity system. In this system, the steam generated in the boiler flows through the pipes to the radiators where it is condensed. The condensed steam in the radiators flows back through the same piping system to the boiler. This arrangement necessitates the condensed steam flowing back against the current of the steam. This is objectionable, as there is a tendency to trap the water. Because of this tendency it is good practice to make the pipes larger in size than would be the case

if the steam and water flowed in the same direction. In the one-pipe gravity system the pipe should always be given a good pitch toward the boiler. Figure 23 shows in diagram the piping and radiator connections for a one-pipe system.

Two-Pipe System.—In the two-pipe system one system of pipes supplies the steam and another system car-

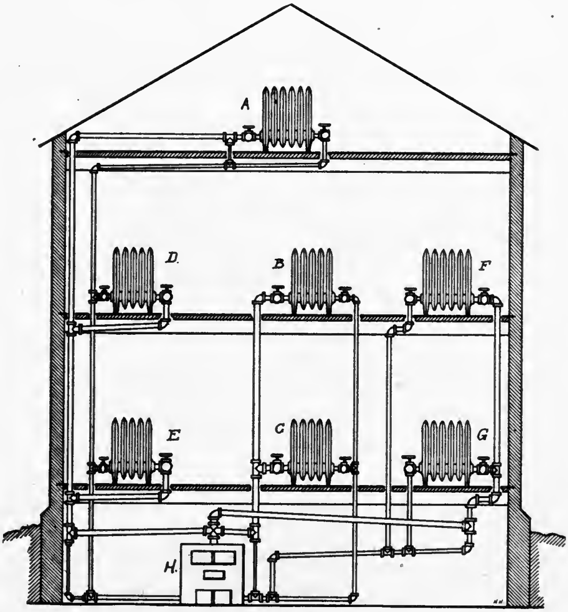


Fig. 24.

ries off the water of condensation. The principal object in the two-pipe system is to avoid the accumulation of any great amount of water in the radiators or mains and in that way give a more positive circulation. Figure 24 shows the general arrangement used in the two-

pipe system. The indirect radiators and pipe coils should always be connected on the two-pipe system.

COMBINATION SYSTEM.—In ordinary buildings the most satisfactory method is to use a combination of the one-pipe and the two-pipe systems. In this system, as

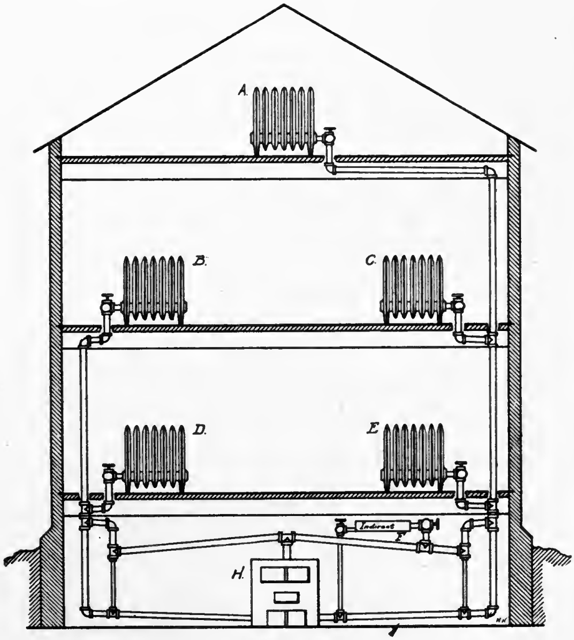


Fig. 25.

shown in diagram in Figure 25, the radiators and risers are on the one-pipe system, while the mains are installed on the two-pipe system. The system has this advantage over the one-pipe system of mains, that the mains are not obliged to carry so much water of condensation and can be freed

from water from time to time. The one-pipe radiator connections of this system are more desirable than the two-pipe radiator connections in that there is but one valve to get into trouble instead of two and the steam and the water of condensation are always in contact with

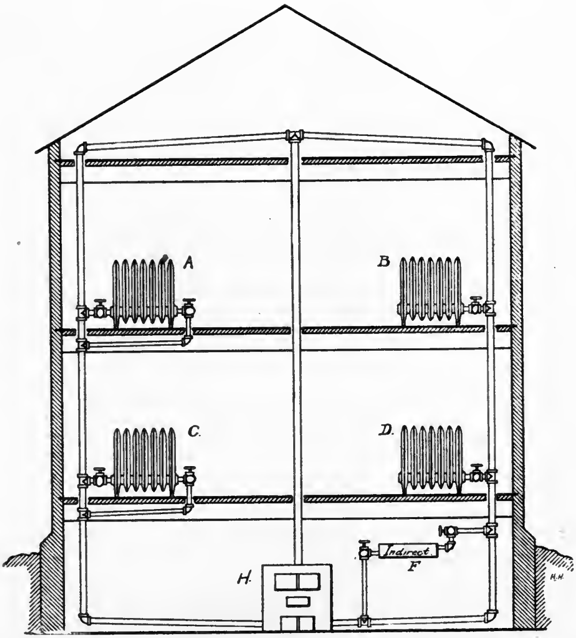


Fig. 26.

each other—thus avoiding the danger of water hammer. The risers may be one-pipe, as it is very seldom that we have difficulty with the circulation in using vertical risers. In most cases the one-pipe radiator connections and two-pipe mains will be found to give the best satisfaction.

Overhead Distribution.—In office buildings and buildings where the basement space is valuable for rental purposes, it is desirable to place the steam mains where they will occupy the least desirable space. It is customary to run a vertical steam main to the attic. A set of distributing mains is run through the attic, from which

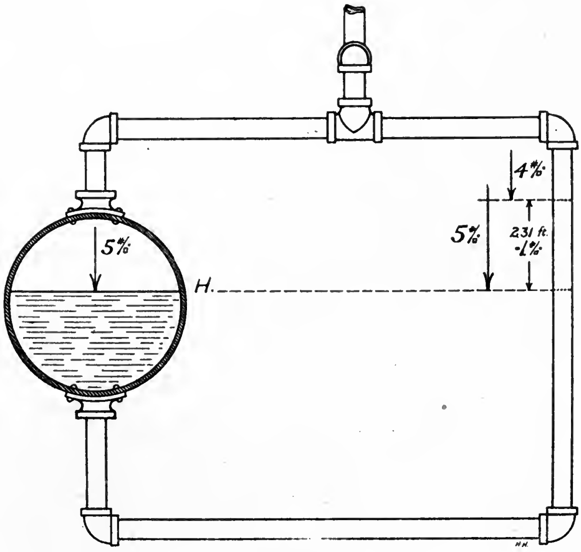


Fig. 27.

vertical risers extend down through the building with drip pipes connecting to the return system at their lower ends. The radiators are connected to the risers by means of single-pipe radiator connections. This system gives very satisfactory results as in all cases the currents of steam and water are in the same direction. In buildings exceeding four stories in height it is usually necessary to provide some form of flexible connection

to allow for expansion. A system of this kind is shown in Figure 26.

GRAVITY SYSTEM.—Figures 23-26, inclusive, are all shown for gravity return system and this system is the one commonly used for all small buildings and for residences. In this system the steam and return mains are connected to the boiler without the introduction of pumps or traps, so that the condensed steam flows back to the boiler by gravity. Figure 27 gives a diagrammatic sketch of such a system. If the pressure at the surface of the water in the boiler is the same as the pressure of the surface of the water in the return mains, then the water level in the return mains and in the boiler will be the same. But if, as shown in Figure 27 by the dotted lines, the pressure in the boiler is 5 pounds and the pressure is only 4 pounds when it gets to the ends of the system, then the system is no longer balanced. It is necessary for the water to rise in the return mains until the column of water in the return mains is of sufficient height so that its weight will equal a pressure of 1 pound per square inch, or approximately, it must rise about 2.31 feet so that the water in the return main will be 2.31 feet higher than the water in the boiler, and this will be true for each 1 pound difference in pressure between the steam at the boiler and the steam at the extremities of the system. It is necessary, then, to be very careful to have ample sized piping in this system so that the pressure at all points of the return main will be about equal. In addition, it is necessary that the steam radiators, both direct and indirect, be at least 2 feet above the water line. For the reasons given above it is not desirable to operate large plants on the gravity return system, as this system requires larger expense for steam

mains and more or less difficulty will always be experienced in starting up the system. The systems of circulation involving traps and pump circulation will be taken up under the head of Central Heating Systems.

Size of Steam Return Mains.—There are a great many rules given for determining the size of steam and return mains, all of which must be more or less modified to meet the particular case in hand. In fact, a very careful determination of the size of main is not necessary, as, no matter how carefully we calculate the size of the main, it is necessary to take the nearest pipe size. In determining the size of the main two conditions must be considered. First, it must be of sufficient capacity to allow of free circulation. This is the principal consideration in smaller buildings. Second, the mains must not produce more than a certain drop of pressure. This point is of particular importance in the design of central heating systems. In the case of residences, the size is determined by rules determined by practice. In the second place, the laws governing the amount of pressure in steam pipes are fairly well known. They will be treated under the head of Central Heating Systems. The most rational method of finding the size of mains is by determining the velocity of steam passing in the main. Knowing the weight of steam passing in the main and having the pressure, the volume of steam passed through the main is known. This volume divided by the allowable velocity in feet gives the area of the pipe in square feet. The velocities allowed in various forms of mains are as follows:

In the steam engine connections from 75 to 100 feet per second.

In exhaust steam mains from 75 to 150 feet per second.

For steam heating work on the one pipe system, pipes 2 inches and under 10 feet per second.

For two-pipe work, pipes 2 inches and under 15 feet per second.

For two-pipe work, pipes 2 to 4 inches 25 feet per second.

For single-pipe work, low pressure, pipes 2 to 4 inches 15 feet per second.

For single-pipe work, low pressure, pipes 4 inches and over 30 feet per second.

EXAMPLE.—Assume that a main is to supply 2,000 feet of radiation. This radiation gives off approximately 1.70 B. t. u. per square foot of radiating surface per degree difference of temperature. Let the tempera ture of the steam be 220°, the temperature of the room 70°. Then the total B. t. u. transmitted per hour will be 220—70×1.70×2,000=510,000. At 220° the latent heat of steam taken from the steam tables equals 966 B. t u. Then the steam used per hour will be 510,000÷966=527 pounds of steam. At 220° each pound of steam has a volume of 22.95 cubic feet. Hence we have 527×22.95=12,000 cubic feet per hour or 3.3 cubic feet per second. For a velocity of 25 feet per second we must have a pipe with an area of .132 square feet or 19 square inches. This is approximately the area of a 5-inch pipe.

Miscellaneous Rules for Size of Steam Main. RULE 1.—The following is a very common rule for gravity return systems: To determine the diameter of the main leading from the boiler, point off two places in the number expressing the radiating surface and take the square root of the remainder. To apply the above rule for indirect surfaces, multiply the indirect sur-

face by seven-fifths and proceed as for direct surface. As an example, suppose we are to supply 2,000 square feet of direct radiation. We point off two places, which gives us 20. The square root of 20 is 4.48, which would make the size of the main 4½ inches.

Table XXVIII gives the common practice in pipe sizes:

TABLE XXVIII.

No. of Sq. Ft. of Radiation on the Main or Riser.	Steam Single Pipe System.	Steam Main Two Pipe System.	Steam Riser Single Pipe System.	Steam Riser Two Pipe System.
50	1½ inch	1¼ inch	1¼ inch	1¼ inch
100	2 inch	1½ inch	1½ inch	1½ inch
150	2 inch	1½ inch	2 inch	1½ inch
200	2½ inch	2 inch	2½ inch	2 inch
250	2½ inch	2 inch	2½ inch	2 inch
300	3 inch	2½ inch	3 inch	2½ inch
400	3½ inch	3 inch	3 inch	2½ inch
500	3½ inch	3 inch	3 inch	3 inch
600	3½ inch	3½ inch		
800	4 inch	3½ inch		
1,000	4½ inch	4 inch		
1,500	4½ inch	4 inch	Very liberal.	
2,000	5 inch	4½ inch		
3,000	6 inch	5 inch		
4,000	7 inch	6 inch		
6,000	8 inch	7 inch		

The steam supply of the radiator should never be less than 1 inch. Steam mains in one-pipe work should not be less than 1½ inches and in two-pipe work less than 1¼ inches. The return connections to radiators should not be less than ¾-inch and return mains should not be less than 1 inch. The drip pipe should not be less than ¾-inch. Long horizontal pipes should be one-pipe size larger than the verticals in the same line. In the overhead system, especially where the building is over seven or eight stories, it is well to make the risers fairly large at the lower end to take care of the condensed steam. These risers, even at the lower end, should not be less than 1½ inches in size.

Return Mains.—Return mains cannot be figured for returning the water of condensation at a low velocity alone, but allowance must be made for the very sudden demands which occur when the plant is started and for the air carried with the water. The size of the return main is determined almost entirely by practical considerations.

Table XXIX gives the relative size of steam and return main and diameter of steam main.

Pipe Drainage.—Return mains may be placed on a dead level, but as a rule it is desirable to give them some slight pitch, to some point, preferably the boiler. At its lowest point there will be provided some sort of drain cock so that all condensed steam may be drained out of the system. The radiators, as well as

TABLE XXIX.—RELATIVE SIZE OF MAINS.

Diameter Steam Pipe.	Diameter Return Pipe.
1½	1
2	1
2½	1¼
3	1½
4	2
5	2½
6	3
8	4
10	4½
12	5

the pipes, should be set so that the condensed steam may drain from them easily. It is always best to drain the condensed steam with the steam, in which case the steam tends to free the pipes of the water of condensation. If mains are long, it is well to drain them at intervals to avoid carrying too much water of condensation with the steam. In the gravity return system where the drip pipes connect to the return system, there should be at least two feet difference in level between the steam main and the boiler water

level, in order to avoid the possibility of the water from the boiler being forced back into the steam main. Check valves will not prevent it, the water of condensation will accumulate in the return main above the check. If it is necessary to drip the steam main at a point below or close to the water line, then it

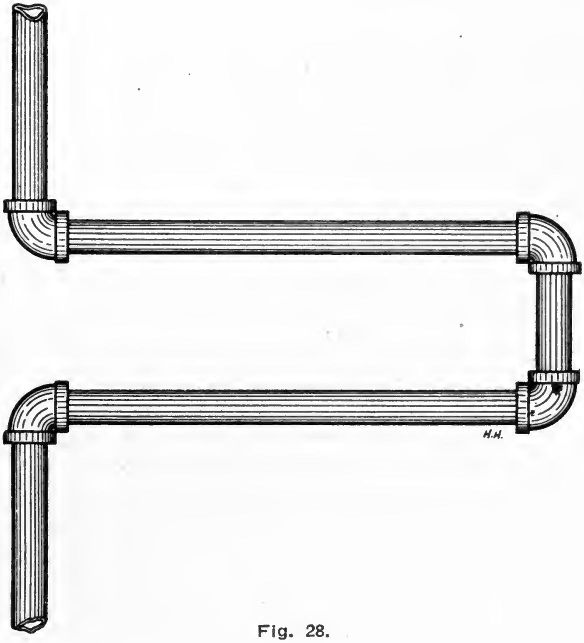


Fig. 28.

should be drained to a separate system of piping and the condensed steam accumulating in this piping should be forced back to the boiler by some mechanical means. Steam connections to steam mains should always be taken from the top of the mains so as to avoid the draining of the water of condensation into the con-

nections. In overhead systems of piping the steam mains may be drained directly through the risers as the amount of condensation is small compared to the number of drain pipes. In this case the risers may be taken from the bottom of the main. In connecting radiators to the pipe system they should be set so as to have a slight pitch in the direction in which they are intended to drain. Radiators set so that they cannot be entirely drained are a very common source of water hammer.

Expansion of Pipes.—The expansion of pipes in mains exceeding 50 feet in length becomes an important consideration. It is customary to assume that in low-pressure steam piping there will be an expansion of 1¼ inches per 100 feet of pipe. In steam mains carrying a pressure of 80 pounds or over it is customary to allow for an expansion of about 1½ inches per 100 feet of length. There are three general methods of taking up expansion.

First, a simple means is by making offsets and turns in the pipe every 100 to 200 feet, the expansion being taken up by the spring in the pipe. This is shown in Fig. 28. This method is seldom used except in pipes under 8 inches. Another method and the method which it is most desirable to use, is to take up the expansion at all 90° turns. In this method the pipe when it reaches the corner turns either up or down and the expansion is taken up by the movement around the vertical nipple in the elbows or tees at the corner. This method of taking up expansion is shown in Fig. 29. The author has had the opportunity of observing a system installed, in which expansion amounting to as high as 4 or 5 inches has been taken up in swing joints of this kind and the joints (which have been in use for over twelve years) have given no trouble whatever.

The third method is by use of expansion joints. The use of expansion joints is in general not to be recommended. Fig. 30 shows a cross-section of an expansion joint. Expansion joints are quite expensive and are always liable to leak and require attention. By carefully laying out the piping most systems can be installed without the use of expansion joints. The most serious difficulty occurs in the modern high office building. In

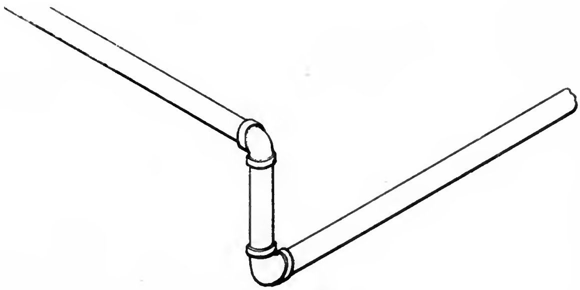


Fig. 29.

buildings of not over ten stories expansion joints may be avoided by anchoring the risers in the middle so that they expand in both directions, and allowing for a flexible connection between the risers and supply main in the attic and return main in the basement. In this case the radiators in the upper and lower stories of the building must have allowance made in the radiator connections for expansion of the main.

Another method that has been used to allow for expansion is by offsetting the pipe at about the middle story. As, for example, in a building of say 16 stories, run the riser up to the eighth story, then offset just under the ceiling of the eighth story for a considerable

distance, usually not less than 20 feet, and continuing the riser up at another location. The principal objection to this method is its appearance. In some cases it is difficult to avoid the use of expansion joints. In using expansion joints, the joint should be anchored so that the expansion will go in a definite direction.

Valves.—A great deal of consideration should be given to the valving of a steam heating system. Gate valves should be used on horizontal steam mains, as they

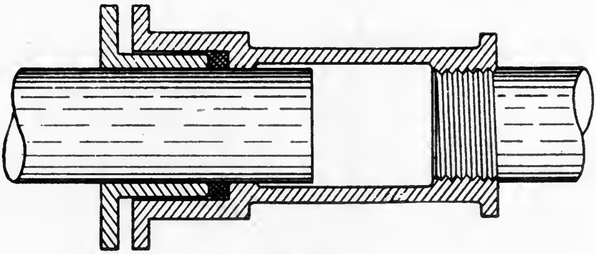


Fig. 30.

do not form a water pocket. If globe valves are used on steam mains, they should be placed horizontally, that is, in a vertical pipe to avoid forming a steam pocket. Where it is possible to use it, an angle valve makes a very desirable form of valve. In large buildings where the plant will be under the control of an engineer, it is desirable to place valves on the steam risers and valves on the corresponding return risers. In residences it is well to avoid valves, particularly on return mains. A valve on the return main is particularly dangerous, as it may be closed by accident while the system is in operation, in which case the radiator will be filled with water and no water will be allowed to return to the boiler.

Location of Mains and Risers.—Mains and risers should be located in as inconspicuous a place as possible, at the same time they should be accessible. The concealing of mains and risers in the building construction is always a questionable practice. If it is necessary to conceal the pipe it should be concealed under panels screwed on so that they can be removed in case of leakage or other necessary repairs. It is not wise to attempt to save in risers by making long radiator connections. The system will give much better operation

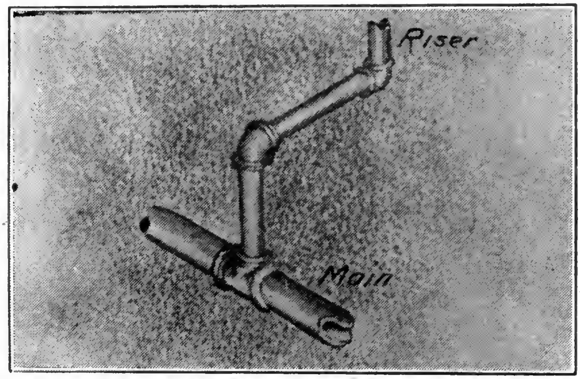


Fig. 31. The Simplest Form of Connection. Not Desirable if Expansion at Right Angle is Great.

by having frequent risers with shorter radiator connections. Where risers are concealed in a building of wooden construction they should be carefully protected from the woodwork.

CONNECTIONS TO MAINS AND TO RISERS.

In making the connections from mains to risers in a steam system there are three things to be considered—the drip, the expansion, and free circulation. The sim-

plest form of connection in shown in Fig. 31, and for general purposes it is perhaps the best form of connection. The expansion of the main in the direction of its length is taken care of by turning in the threads of the vertical pipes. The expansion at right angles to the main, which is ordinarily very small, is taken care of by the spring of the pipes. If the expansion occurring at right angles were very large, then some other form of connection would be desirable.

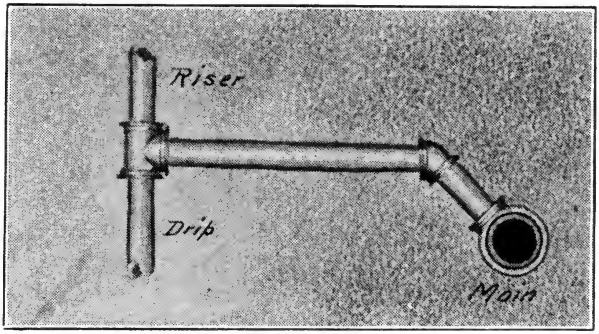


Fig. 32. Using a 45° Ell Instead of a 90°, as Shown in Fig. 31.

Fig. 32 shows a similar connection, but using a 45-degree elbow in space of a 90-degree elbow at the main, as shown in Fig. 31. This connection offers less resistance to the passage of steam than the connection shown in Fig. 31; on the other hand, it does not allow of as much expansion. The pipe rising from the main being at 45 degrees, there is a limited opportunity for any turning in the threads of the pipe and expansion is taken up by the spring of the pipe. In this figure a drip is shown at the bottom of the riser. A drip is often placed at this point, particularly in large buildings. In smaller

plants condensation is carried back through the steam connection itself, as in Fig. 31. In larger buildings it is undesirable to carry so much condensation through the horizontal pipes and a drip is placed at the bottom of the riser, as shown in Fig. 32.

Fig. 33 shows a connection similar to that in Fig. 31. It allows free expansion of the main, the same as Fig. 31. In Fig. 33 all the condensation which has occurred

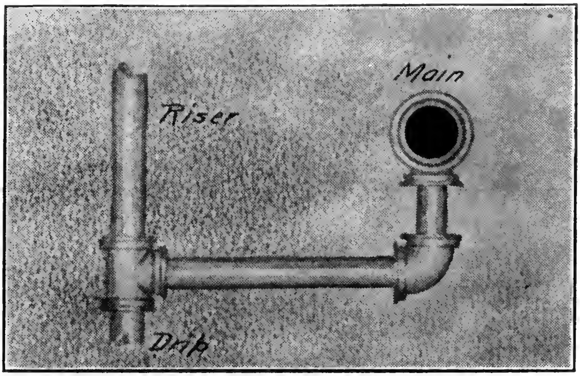


Fig. 33. Allows for Expansion of the Main; Requires a Drip at the Point where Riser Starts.

in the main up to this connection will drain into the connection and it is therefore necessary to place a drip at the point where the riser starts. A connection of this kind is often used where it is desired to meter different riser connections for different consumers, then the condensation for each riser or each set of risers can be collected and metered with very little possibility of its coming back into the main. This is, in some respects, an undesirable form of connection. If for any reason the water level rises in the return system above the horizontal pipe connection to the riser, then the riser will be

entirely sealed from the main and it will be impossible to get steam into the riser. The writer has experienced this difficulty in places where it was necessary to use this

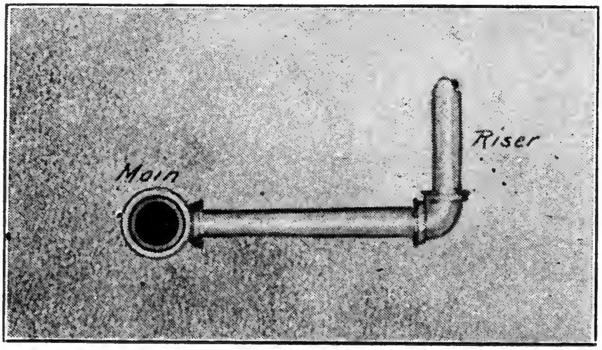


Fig. 34. Often Used in Limited Headroom. Usually Undesirable.

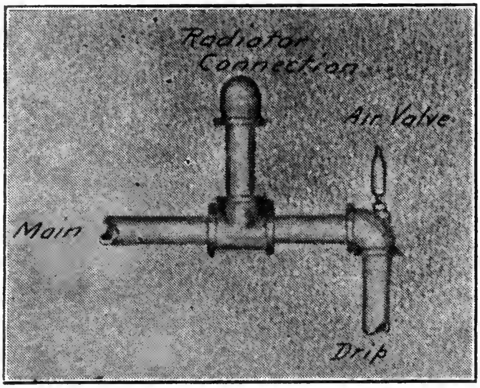


Fig. 35. A Different Way of Carrying Off the Drip; Used Where Drip is Taken Off at End of Main.

form of connection. This happens particularly in gravity return systems.

Fig. 34 shows a form of connection often used where

there is very limited head room. As a general rule this form of connection is a very undesirable one. It allows almost no expansion, all expansion in such a connection must be taken up in the spring of the pipes. In addition to this, if the main happens to carry a large amount of water of condensation, part of this condensation may flow into the horizontal pipe and impede the circulation in the horizontal. Under the same conditions if a connection such as is shown in Fig. 31 or Fig. 32 were used, no difficulty would be experienced.

Fig. 35 shows another method of carrying off the drip. This arrangement is used where the drip is to be taken away at the end of the main. It is very often desirable at such points, particularly if the main is long, to remove the air from the pipe. The figure shows an air valve placed at the end of the pipe. Locating an air valve at the end of a main near the point of the drip facilitates the rapidity of the circulation in the main. In a great many installations all the air in the system is taken care by means of the radiator air valves. Such an arrangement, particularly if the house be large, always makes the system slow in circulation. In the larger systems it is absolutely imperative that the steam mains be properly relieved of air. In addition to making the steam slow in circulation, it causes unequal expansion of the piping. This trouble will be taken up in another chapter.

Fig. 36 shows the connection of the drips from two mains to a single drip pipe. Such an arrangement, while simple, is undesirable, as the condensation from one main often interferes with the condensation coming from the other main. This would give very little trouble if the connection were made above the water line. The ob-

jection, however, to making such connection above the water line is that if the two currents of condensation which meet at this point are not at the same temperature, hammering or a chattering noise results. If placed

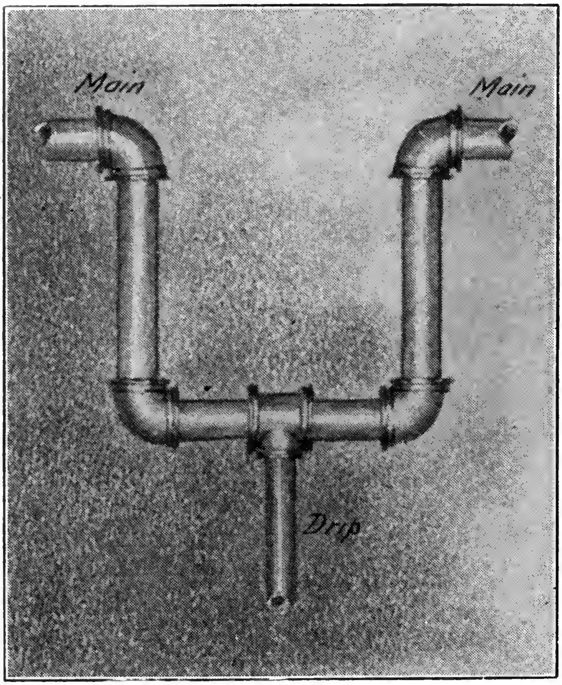


Fig. 36. Drips from Two Mains to a Single Drip Pipe. Simple but Undesirable.

below the line there is an opportunity for the two streams of water to interfere with the circulation.

A better arrangement is that shown in Fig. 37, in which the two streams of water coming as drip from the steam mains would not strike each other in the same

line; the one stream would flow into the other. The union of the two streams should occur below the water line of the system, if possible.

Fig. 38 shows a connection from main to riser, in

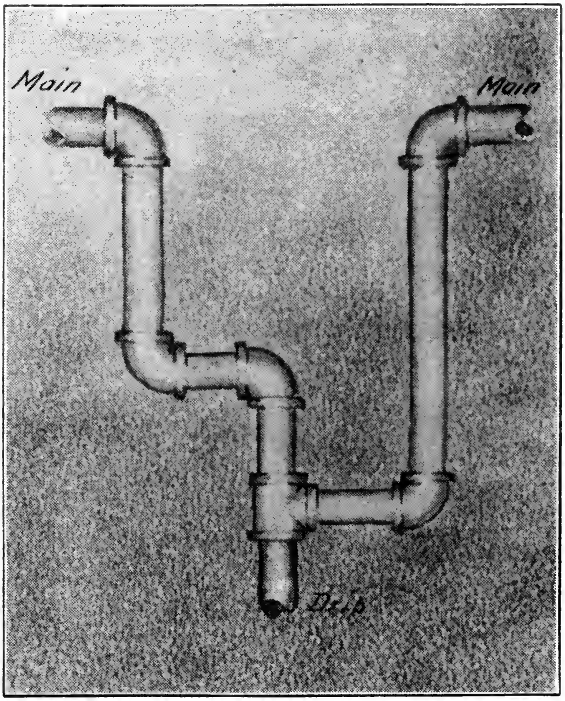


Fig. 37. A Better Arrangement of Dripping Two Mains into One Drip Pipe.

which the head room is very short and it is desired to take up a large amount of expansion, the expansion being taken up by a swing on the short vertical nipple and by a swing on the riser. This connection has been used

for tunnel mains where the head room in the tunnel did not permit of the other forms of connection shown.

Fig. 39 shows the connection between the main and the riser in an overhead system of distribution in which

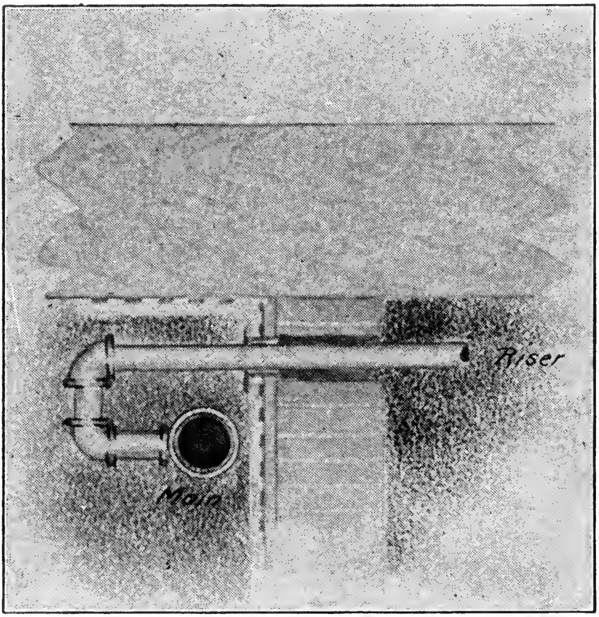


Fig. 38. Connection from Main to Riser Where Headroom is Very Short and Expansion Great.

the rooms in the upper story are used and it is desired to conceal the piping connections.

As shown in Fig. 39, the connection from the main to the riser is carried in the space between the roof and the ceiling of the room below. The connection from the main to the riser is taken from the bottom of the main. This is not objectionable in an overhead system, as each

riser has a drip at the bottom and becomes in itself a drip main, and in some cases this is the desirable thing to do, as it keeps the steam and main entirely relieved of condensation at all points.

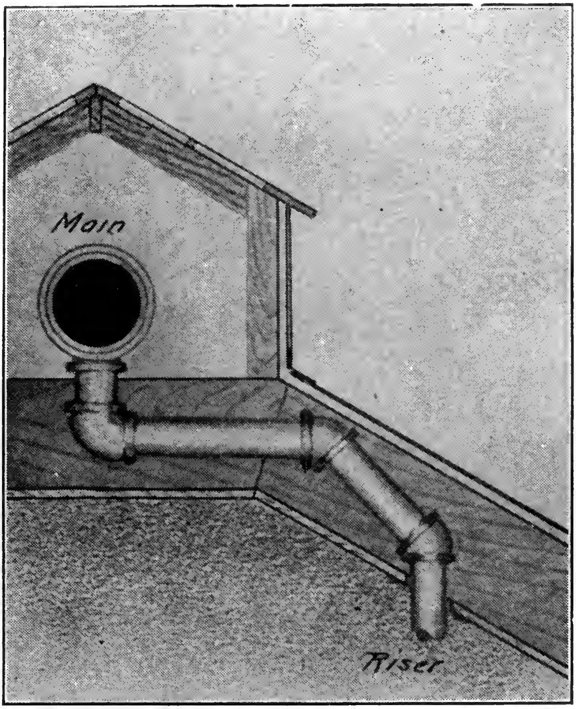


Fig. 39. Connection from Main to Riser in Overhead System of Steam Distribution.

In making connections between mains and risers an endeavor should be made to locate the main so that the horizontal pipe connecting main to the riser will not be too long, just enough to allow for expansion. If it

is necessary to make this a long pipe, then the pipe should be made one pipe size larger than would otherwise be used, particularly in the single pipe system. In the double pipe system long horizontals are not so ob-

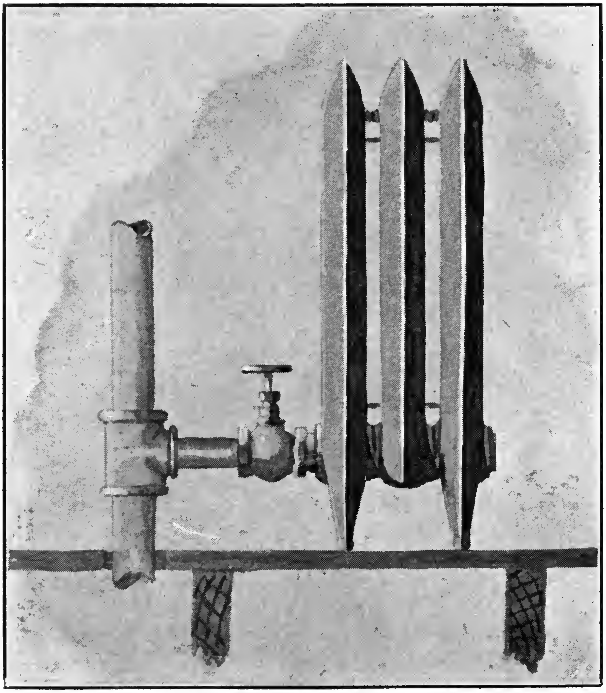


Fig. 40. Simplest Form; Short; Drains Easily, but Does Not Allow for Expansion of Riser.

jectionable, as the riser may be dripped at its lower end, as shown in Fig. 32.

In residence work it is usually found desirable to connect directly from the steam main to the radiators

on the first floor instead of connecting these radiators to the risers. This direct connection from the radiator to the main insures a quicker circulation of the first floor radiators, which is usually found desirable in residence work. In building work this is not usually the

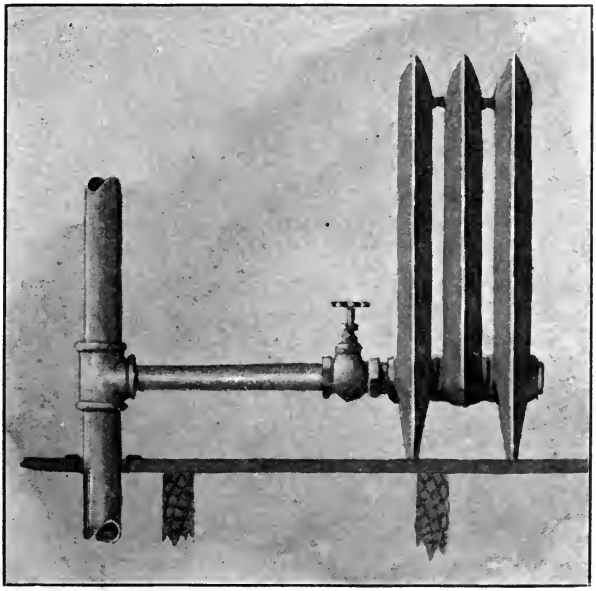


Fig. 41. Horizontal Connection Long Enough to Care for Some Expansion of Riser by the Spring of the Pipe.

case, the first floor radiators are connected to the main risers.

Radiator Connections.—The connection between the radiators and the risers should always be carefully considered. There are a great many forms of connection used between the radiator and the riser to which it

is connected. Each of these different forms of connection has its advantage and disadvantage, which must be considered in using any particular type of connection. Figures 40 to 46 deal with single pipe work.

Fig. 40 is the simplest form of connection. Its advantage is that it is short, simple and drains easily. The

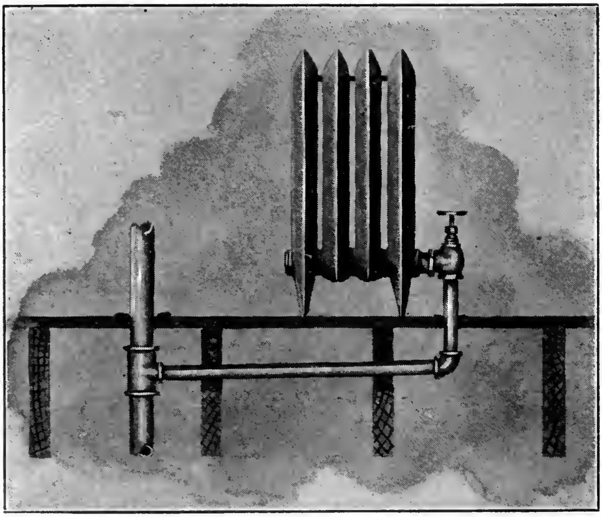


Fig. 42. Desirable, Clean, but Floor Must Come Up When the Trouble-Man Comes.

disadvantage of this form of connection is that it does not allow of any expansion.

The expansion of the riser would lift one end of the radiator off the floor and in all probability produce a leaky joint.

Fig. 41 is a similar form of connection, but the connection between the valve and the riser is long enough so that a certain amount of expansion can be taken care

of by the spring of the pipe which connects the radiator valve and the riser.

Fig. 42 is a very common form of connection used in residence work. The advantage of this connection over the connections shown in Figs. 40 and 41 is that where the pipe passes over the floor there is always opportunity for dirt to collect around and under the pipe and it is difficult to sweep this dirt out. The connection shown places the horizontal pipe in the joist space.

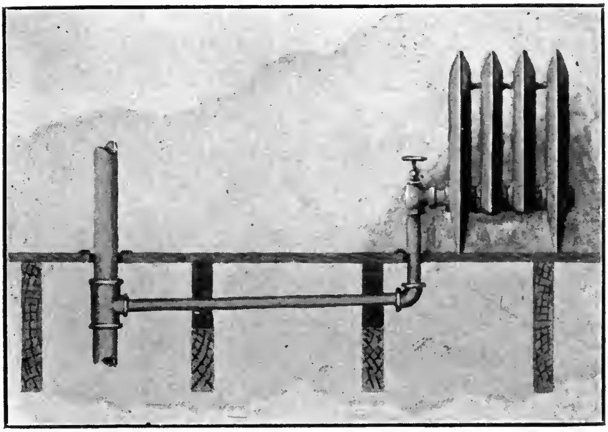


Fig. 43. Similar to Fig. 3, with Position of Radiator Changed.

The long horizontal pipe under the floor allows a certain amount of expansion due to the spring of the pipe. On the whole this is a desirable form of connection. Its principal objection is that it cannot be easily reached in case of accident and it cuts the joists. The most common trouble with such connection is to have a sand hole in the elbow. Of course to repair this it would be necessary to take up the floor.

Fig. 43 is practically the same as Fig. 42, the position of the radiator being changed.

Fig. 44 shows the arrangement of radiator connection in which the horizontal is dropped down under the ceil-

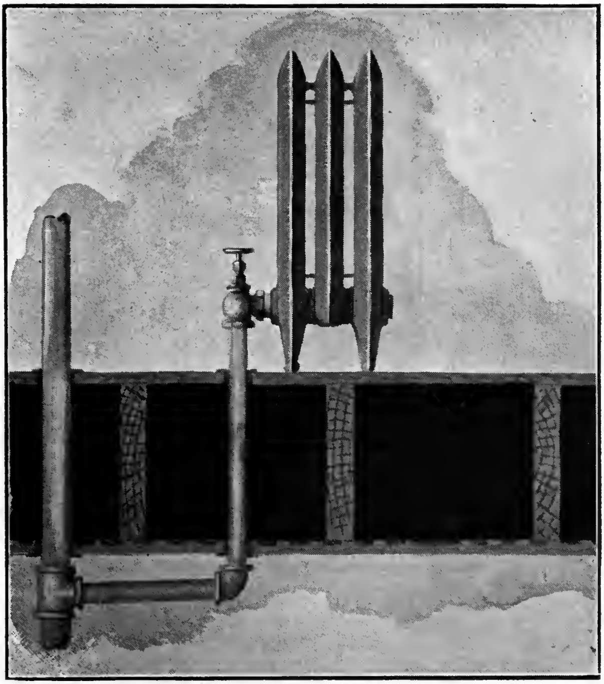


Fig. 44. Sometimes Used on Upper Floors, Horizontal Pipe Exposed Below Ceilings Is An Objection. Will Do for Store Undecorated Rooms.

ing of the room below. This connection is sometimes used on upper floors. The objection to it, however, is that the horizontal pipe coming just below the ceiling is very unsightly, and it should be used only where the

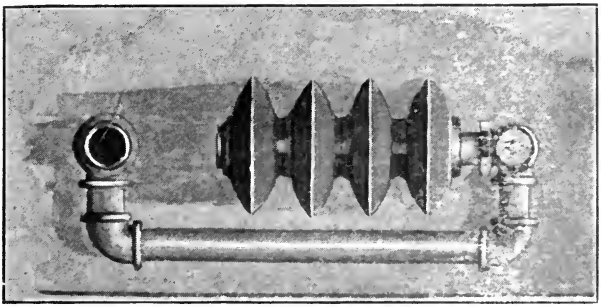


Fig. 45. Used in Office Buildings; Good Form for Fireproof Buildings.

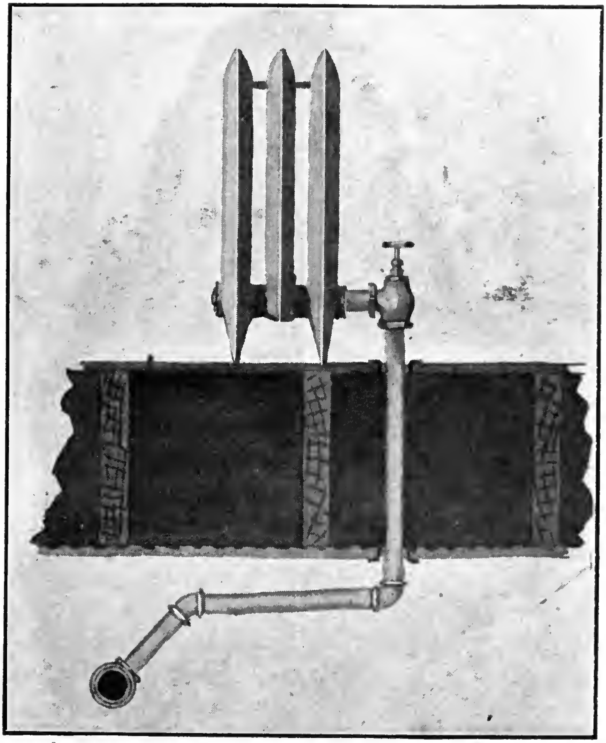


Fig. 46. Commonly used in Residence Work, Where First Floor Radiators are Fed from Main in Cellar.

horizontal pipe is exposed in store-rooms or through undecorated rooms where such pipe would not be objectionable.

Fig. 45 is the plan of a connection very commonly used in office buildings. The connection is made from the riser to the radiator, passing the pipe behind the radiator and using a corner valve where the radiator

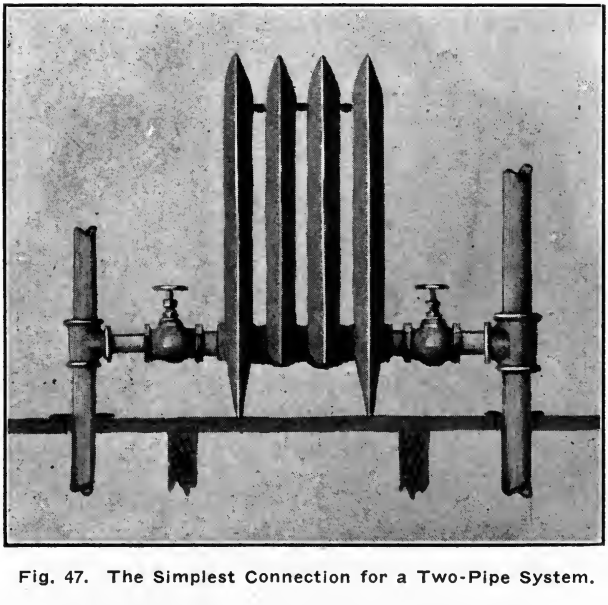
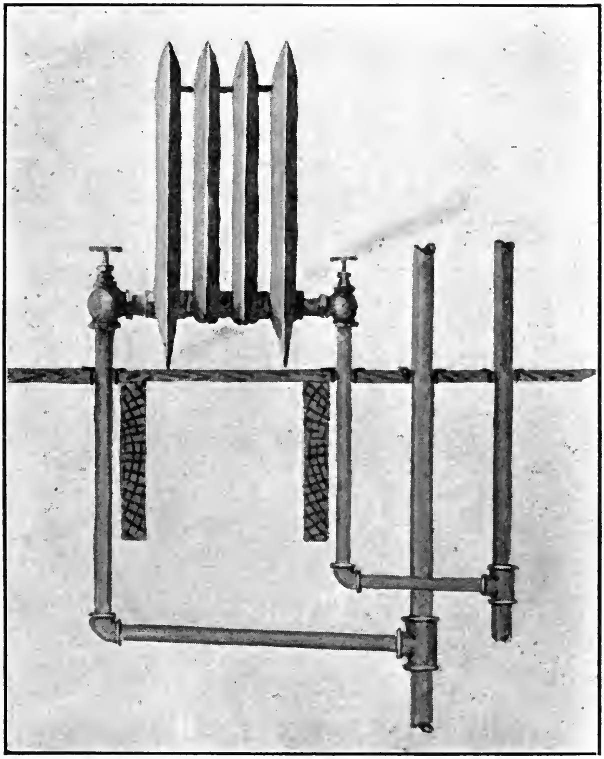


Fig. 47. The Simplest Connection for a Two-Pipe System.

connection attaches to the main. The principal objection to this arrangement is that it throws the radiator out some distance into the room and it is very difficult to sweep around the connection so as to keep it clean. In buildings of fireproof construction and where a large amount of expansion is to be taken care of, this is probably the best form of connection to use.

Fig. 46 shows a connection similar to Fig. 44 for first floor radiators. It is customary in most buildings to connect the first floor radiator directly to the main and not to a riser. This arrangement is commonly used in resi-



In Buildings Not More Than Three Stories in Height.
Fig. 48. Expansion Taken Up by Spring in Horizontal Pipes. Used

dences. The connection is such that we have very easy turns and a very slight resistance for the passage of condensation.

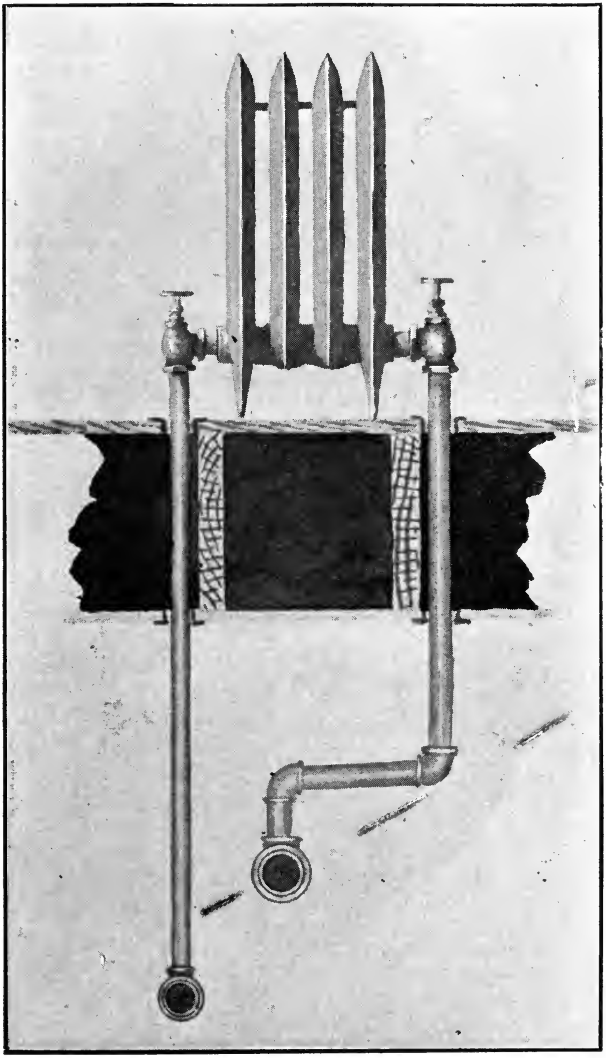


Fig. 49. Radiator on First Floor and Horizontals in Basement.

Fig. 47 shows the simplest form of radiator connection for the two-pipe system. The objection to this arrangement is similar to the objection made to Fig. 40. That is, it is very rigid and will permit of almost no expansion and should only be used where the radiator is located at such a point that it is not necessary to take up expansion. The connection is simple and direct, and from the standpoint of circulation, a desirable one.

Fig. 48 shows a connection in which the expansion is taken up by means of the spring in the horizontal pipes. The verticals to the radiator valves may be made shorter and these connections can all be concealed in the joist space if desired. This arrangement can be used for buildings not more than three stories in height. Where buildings are higher the two-pipe connection should be made with a series of elbows, allowing for free expansion—something like that shown in Fig. 45.

Fig. 49 shows a two-pipe radiator connection where the radiator is on the first floor and the horizontals are located in the basement. The same connection is shown with a horizontal pipe, allowing for expansion. In this case the return connection is shown entering directly into the return main without any elbow. This is always undesirable, as the connection is very rigid, not allowing for expansion, and should only be used where the connection will not be affected by expansion. If expansion must be allowed for in the return main then a connection similar to that shown for the steam main should be used.

Fig. 50 shows the radiator connection for automatic system of heat control on the double-pipe system. In this case it is quite common to put the automatic valve on the steam supply and the check valve on the return.

Then when the steam is turned off by the thermostat, the check valve automatically closes, and there is no possibility of the steam or water in the return main

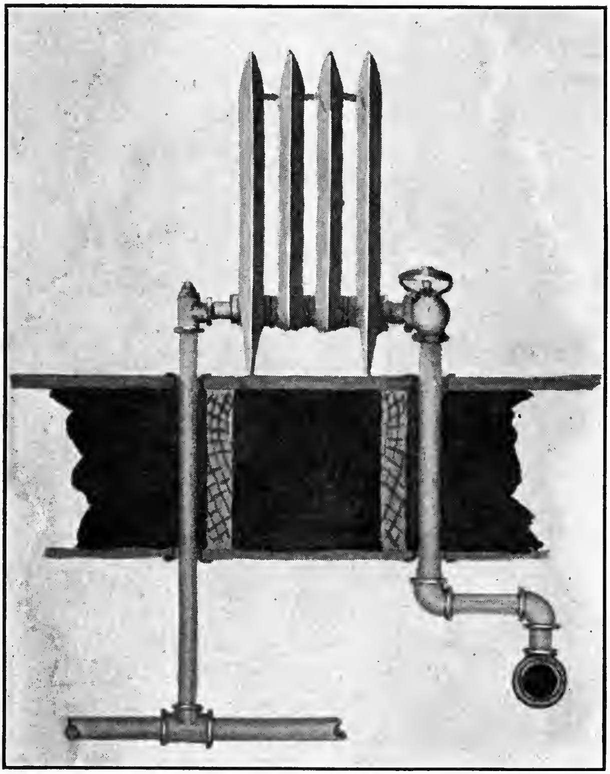


Fig. 50. Connection for Automatic System of Heat Control on the Double-Pipe System.

getting back into the radiator. If no check were placed upon the return a vacuum would be formed in the radiator, due to the condensation, and the water would be

drawn back from the return main into the radiator by this vacuum; then when the steam was again turned on this water would cause a severe hammer in the radiator. A still better arrangement is to put an automatic valve on both supply and return.

In planning radiator connections for a building a long horizontal should be avoided, the length should be only sufficient to take up expansion.

The location of the radiator should be carefully selected, so as not to occupy the best space in the room. For example, it is not uncommon to find the radiator in a bedroom occupying the only place in the room for the bed. The position of the radiators should be selected also with reference to the risers, so as to make the connections as short and direct as possible. The form of connection should be such as to allow for proper expansion.

Supporting of Pipes.—Horizontal pipes are usually supported by the ordinary form of expansion hanger. As a rule pipes should be supported every 10 feet and should be supported at points bearing the greatest weight. In placing a pipe support care should be taken to see that each support bears its proper proportion of weight. In buildings over three stories in height means should be taken to carry the weight of the risers. An iron strap passing around the pipe and bolted to some portion of the building structure is usually the best means. Large piping is often supported by chains or on brackets with rollers. The supports of large pipes will be taken up under the subject of Central Heating.

CHAPTER VII.

DESIGN OF A HOT WATER HEATING SYSTEM.

Hot water heating plants may be divided into two classes, those using natural circulation, and those using forced circulation. In residences and small buildings the system using natural circulation is almost universally used. It is simpler in construction and cheaper to install and operate. In central hot water heating systems and in the larger buildings the forced system of circulation is employed. It is more certain in circulation, the size of the pipes may be smaller and in such buildings the system may be cared for by an expert attendant. The systems of forced circulation will be discussed in connection with central heating.

Natural System.—The arrangement of the hot water boiler and of the piping in a hot water heating plant is similar to that of a two-pipe steam system, the difference is only in minor changes in the piping system. The circulation in a natural hot water heating system is produced by the difference in the weight of the water in the cold and the hot leg of the system. It depends very largely upon the height of the water column in the cold leg. The difference in the weight of the water in the two legs of the system is due to the fact that water weighs less per cubic foot as its temperature is increased, namely:

At 130° the weight of water per cubic foot is 61.56 pounds. At 140° the weight of water per cubic foot is 61.37 pounds. If, then, there were one cubic foot of

water in both hot and cold legs of the system with a difference of 10° between the two sides, the force to produce circulation would be .19 pound. It will be seen from this that the force going to produce circulation is a small one and may be easily overcome by the resistance of the piping system. It is important, then, that in installing a hot water system considerable attention be given to the arrangement of the piping.

Loss of Heat from Radiators.—In designing a hot water system the losses of heat from the building would be computed by the same rules as previously given for other systems. These losses of heat having been determined, it will be necessary to replace the loss by the heat given off by the radiator. In order to determine the amount of radiation necessary we must know what the losses of heat per square foot are for hot water radiators. Table 30 gives the results obtained from hot water radiators tested under actual operating conditions with hot water.

Table XXX shows that the rate of transmission, as given in the last column of the table, is almost the same as for steam radiators. It will be safe to assume that

TABLE XXX.

Kind of Radiator.	Temp. in hot leg.	Temp. in cold leg.	Temp. of Room.	Loss in B. t. u. per sq. ft. per hour.	Loss in B. t. u. per sq. ft. per hour per deg dif. in temp.
38″ 3-column cast iron	187	182	72	180	1.67
38″ 2-column cast iron	190	185	70	200	1.70
38″ flue radiator	182.5	178.5	70	181	1.65
38″ 2-column cast iron	172.5	167.5	70	150	1.50

the hot water radiator would give off the same amount of heat per square foot whether filled with steam or hot

water, the temperature inside and outside of the radiator being the same. This, however, is not the case, as it is customary to operate a hot water plant at a temperature not exceeding 180° or less. In calculating heating surfaces, the temperature of the water should never be assumed higher than 170°. The temperature being about 220° under ordinary conditions in a steam radiator and only 170° in the hot water radiator, the total transmission in the hot water radiator is only about 65 per cent of the transmission by the steam radiator using steam.

There is another consideration in hot water heating. The lower the temperature of the radiating surface the more uniform the temperature of the room and the more agreeable the heating effect. Where it is desired to heat almost uniformly all portions of a room, regardless of initial expense, it may be accomplished by installing very large heating surfaces. The reason for this is easily explained. Where the radiating surfaees are kept at a high temperature, say 200° or over, at least 50 per cent of the heat is given off by radiation and the remaining heat is given off by contact of air. When the temperature of the radiating surface is lowered a large proportion of heat is given off by contact of air and a smaller portion by radiation. This allows the air in the room to be at nearly the same temperature as the objects in the room. It is possible, then, in a hot water system to use quite different amounts of radiation, depending upon the effect desired. This may be illustrated by an example.

INDIRECT HOT WATER RADIATORS.

Suppose a room to lose 10,000 B. t. u. per hour and that the heating surface has the same rate of transmission whether steam or water is used, and that

this rate of transmission be 1.5 B. t. u. per square foot per degree difference of temperature. In the first case, let the room be heated by steam. The temperature of steam in the radiator be 220° and the temperature of the room 70°. Then the heat loss per square foot of surface would be (220—70) × the rate of transmission, 1.5 = 250 B. t. u. The number of feet of radiation required to heat the room will be 10,000÷250=40 sq. feet.

In the second case, suppose the room to be heated by hot water radiator at a temperature of 170°. Then the B. t. u. given off per square foot of surface would be (170—70)×1.50=150. The number of square feet of radiation required to heat the room would be 10,000÷150=66 square feet.

In the third case, assume a residence in which a very uniform heating condition is desired and the temperature of the heating surface is not to exceed 150°. The loss per square foot of radiation would be (150—70)×1.50=120 B. t. u. The radiation required would then be 10,000÷120=83 square feet. The amount of radiation in hot water heating depends, then, upon the effect desired.

In a closed tank system it would be entirely possible to obtain a temperature as high as 240° or 250°. In the open tank system the temperature should never exceed 180°, as a higher temperature than this would form steam in the tank and there would be danger of the water boiling, which causes a cracking, hammering sound in the piping system.

TABLE XXXI.—INDIRECT HOT WATER RADIATORS.

The following table gives the emission of heat by indirect hot water radiators per square foot per hour per degree difference in temperature:

Velocity of Air in Feet Per Minute.	British Thermal Units.
174	1.70
246	2.00
300	2.22
342	2.38
378	2.52
400	2.60
428	2.67
450	2.72
474	2.76
492	2.80

The difference between 170 degrees (average temperature of the water in the radiator) and 55 degrees (average temperature of the air passing through the radiator) being 115, the efficiency at 240 feet velocity per minute is 2. B. t. u. per degree difference or 230 B. t. u.

Ordinarily the amount of indirect radiation required is computed by adding a percentage to the amount of direct radiation, and an addition of 50 per cent has been found sufficient in many cases. When accurate results are required it is better to figure the heat loss as given in Table XXXI.

Free area between the sections of radiation to allow passage of the required volume of air at the assumed velocity must be carefully maintained. The cold-air supply duct, on account of less frictional resistance, may ordinarily have 80 per cent of the area between the radiator sections. The hot air flues may safely be proportioned for the following air velocities per minute: First floor, 200 feet; second floor, 300 feet; third floor, 400 feet.

Rules for Hot Water Heating.—Rule 1.—Divide the volume of the room by 55. Add ¼ of the exposed

wall surface. Add the glass surface. Multiply the sum of these by .4, the product will be the square feet of direct hot water radiation required.

Rule 2.—For ordinary rooms divide the exterior wall surface by 4; add the glass surface and multiply the sum by .55. For entrance halls multiply the sum by .7.

Rule 3.—Divide the volume of the room in cubic feet by the factors given below and the quotient will be the radiating surface in square feet.

First floor rooms, 1 side exposed...............40
First floor rooms, 2 sides exposed..............37
First floor rooms, 3 sides exposed..............34
Second floor rooms ....45—50
Halls and bath rooms 35
Offices ....37—50

In all these rules factors of exposure are to be allowed as given on pages 21 to 27.

In order to understand better the methods of determining the heating surface required for a given house, take the same house as figured for steam on page 77.

TABLE XXXII.—RESULTS OF COMPUTATIONS—DIRECT HOT WATER.

	B. t. u. from Table XII.	Radiating Surface, 2-Column Cast Iron.	Radiating Surface Rule 3.	Radiating Surface Actually Installed.
First Floor—				
Parlor	10,395	68	45	68
Sitting room	7,035	46	52.5	50
Dining room	7,350	48	48	48
*Kitchen	10,300	67.5	47	40
Hall	7,035	46	32.5	48
Second Floor—				
W. chamber	10,050	65	39	65
Alcove	7,560	49	18	40
S. chamber	7,035	46	34.5	46
N. chamber	7,455	49	32	50
Bath	3,150	20	12	20
E. chamber	5,250	34	25	34
Halls	2,730	18	25	20

*Just enough radiation to keep from freezing in extremely cold weather.

In Table XXXII the second column gives the B. t. u., as determined in Table XXI, column 3. Column 3 gives the radiation in square feet for a two column radiator. Column 4 gives the radiation as determined by Rule 3, the volume rule, the volumes of the rooms being taken from Table XX. Column 5 gives the radiation that would actually be used. The quantities in column 3 are obtained as follows: Assume the average temperature of the water in the radiator is 170°. The temperature in the room is 70°, the difference is 100°. The rate of transmission as given in Table XXX, line 4, is 1.50 B. t. u. The total transmission per square foot per hour is, then, $1.50 \times 100 = 150$ B. t. u. Dividing the heat lost from the room, column 2, by 150, or the loss for each square foot of radiation, will give the results in column 3, the number of square feet of radiation required. In column 4 the radiating surface has been determined by the volume rule, Rule 3, and shows the inconsistency of this method of figuring, though it is a method very commonly used. This method should never be used except as a check. When the volume rule shows very much larger results than the other rules it is well to add surface to the radiator to allow for heating the air in the room. This has been done in column 5. In regard to proportioning of radiation one can never trust absolutely to his figures and should always carefully compare his results with the room and its exposure and use his judgment in regard to radiation that seems desirable.

CHAPTER VIII.

HOT WATER BOILERS AND PIPING.

Hot Water Boilers.—Hot water boilers are practically the same as steam boilers. Any good form of steam boiler may be changed to a hot water boiler by filling the steam space with water and allowing the water to go in at the lowest point of the boiler and go out at the highest point of the boiler. In boilers especially designed for hot water heating no space is left over the tubes, the whole boiler shell being filled with tube surfaces. This makes the hot water boiler more compact for the same amount of heating capacity than the steam boiler. The circulation in the hot water boilers is probably slower than in steam boilers and there is much less local circulation. The cold water enters from the bottom, passes over the tubes and leaves at the top of the boiler. The heat transmitted per square foot of surface is practically the same in steam and hot water boilers. The proportions of heating surface to grate surface and of grate surface to chimney area may be taken the same for hot water as for steam.

In large hot water systems the ordinary fire tube boiler is used. The principal modification of the boiler would be to fill the steam space with tubes and make the return opening same size as the steam opening. For residence work cast iron, sectional boilers are usually used and these are suitable for all similar work, except where high pressure is used. In high pressure hot water heating, cast iron boilers are not permissible, as these boilers are not usually made to withstand pressures exceeding 20 pounds. A pressure of 20 pounds corre-

sponds to a water column 46 feet high and this is about the height of an ordinary four-story building. It is not desirable to use cast iron boilers in buildings more than three stories high, above that height wrought iron boilers should be used so as to withstand the static pressure due to the height of the water. Cast iron boilers would not be suitable for hot water systems using a closed tank and having the water under pressure. Boilers for these systems are usually made to withstand safely a pressure of 100 pounds per square inch. The proportions of cast iron boilers for hot water heating are given in Table XXXIII. In this table the rating of the boiler does not include the piping. In selecting the boiler the square feet of radiation equivalent to the piping must be added to the square feet of radiator surface. In the average house these boilers will carry .6 of their rating in actual radiation, exclusive of piping, provided the piping is covered with some good grade of pipe covering.

Hot Water Piping.—In designing a hot water piping system the most important consideration is the resistance of the piping. The resistance of the piping should be almost the same for each radiator at the same level and the friction of the piping system should be kept as low as practicable.

Definition of Terms Used.—The different parts of the piping system referred to will have the following meaning:

Flow Mains and Risers.—The flow mains and flow risers are those portions of the piping system which carry hot water from the boiler to the radiator. The word *flow* always refers to the hot side of the system.

Return Mains and Return Risers.—The terms re-

turn mains and return risers refer to piping which returns the cold water from the radiator to the boiler.

Expansion Tank.—The expansion tank is a vessel partly filled with water and partly filled with air, which allows for the variation of the volume of water in the system with the changes of the temperature of the water. In the open tank system this tank is situated at the highest point of the system. In the closed tank system it may be located anywhere in the building.

TABLE XXXIII.—PROPORTION OF CAST IRON HOT WATER BOILERS.

Sq Ft. of Radiation Boiler will Carry.	Sq. Ft. of Heating Surface.	Sq. Ft. of Grate Surface.	Size of Pipe Connections.	Smoke Flue.
150	25	1	2	8
230	30	1.3	2	8
375	40	1.6	2½	9
500	60	2.5	2½	9
860	80	3.3	3	9
1,300	120	5.0	3½	10
2,000	160	6.5	4	11
2,500	200	8.5	5 or 2-3½	12
3,000	250	10.0	6 or 2-4	14
3,500	280	11.5	6 or 2-4	16
4,000	330	13.5	6 or 2-5	18
5,000	400	16.5	7 or 2-5	26
6,000	500	20	8 or 2-6	22
7,000	575	23	8 or 2-6	24
8,000	650	26.5	2-7 or 3-5	26
9,000	750	30	2-7 or 3-5	26
10,000	800	33.5	2-8 or 2-6	28
11,000	900	36.5	2-8 or 2-6	28

Pitch.—The pitch of the pipe refers to its inclination from the horizontal.

Legs of the System.—The flow main is often termed the hot leg of the system and the return main the cold leg of the system.

Systems of Piping.—Four systems of piping are used—the multiple circuit system, the single circuit system, the overhead system, and the single pipe system.

Multiple Circuit System.—This system is the one most used and is sometimes called the standard system of piping. This system is shown in Fig. 51. The flow

main rises from the top of the boiler to a convenient height just below the basement ceiling so as to allow

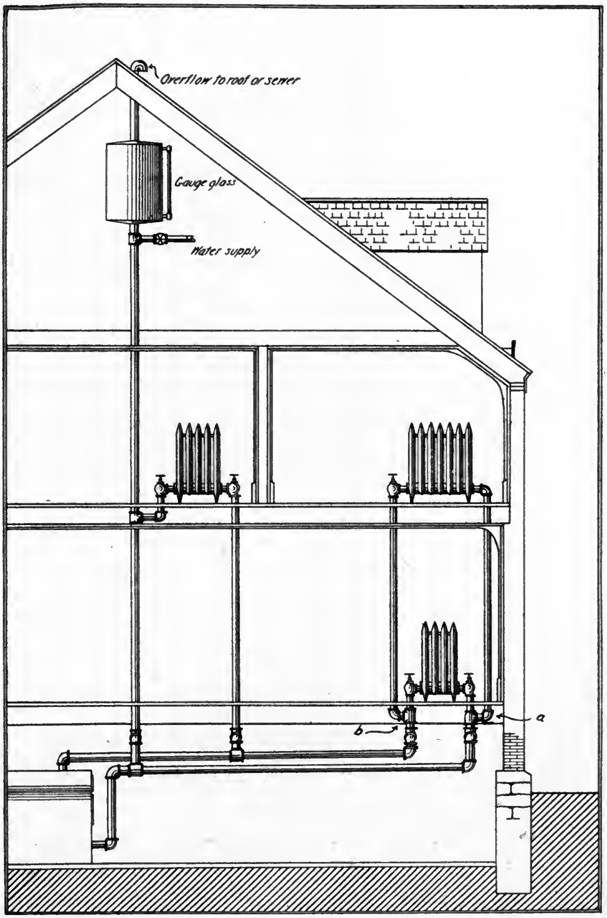


Fig. 51.

for pitch towards the boiler of not less than ½ an inch in 10 feet. This main or mains is carried around the

basement so as to supply the risers. Too many risers should not be taken from one set of mains, as the radiators at the end will be too much cooled. The main return is parallel to the flow main and of the same size. The open expansion tank is placed at least 3 feet above the last radiator and should be connected to the nearest riser. The connection to the expansion tank should be at the bottom of the tank. In this system the branches from the flow main usually supply only one radiator on the first floor, a separate branch being run to the radiators on the second and third floors. At the points A and B, Fig. 51, where the riser branches to go to the second floor, the risers offset. This is done to prevent too rapid circulation in the radiators above the first floor, the tendency being for the second floor radiators to take all the water and prevent circulation in the first floor radiators. This is a reason why it is preferable to connect first and second floor radiators separately to the flow main. The circulation in the hot water system depends upon the vertical weight of the system. The higher the main the more rapid the circulation. This makes it necessary to put additional turns in the risers going to the upper floors or add to the resistance in the piping system so as to make the resistance to each floor proportional to the effective head producing circulation at that floor.

Single Circuit System.—In the single circuit system, as shown in Fig. 52, the water flows directly to the radiator from the boiler through a pipe to which no other radiator is connected and is returned to the boiler by a separate pipe. A large number of these circuits may be connected to one boiler, each one being entirely separate from the other. This is one of the earliest forms of piping systems used for hot water work. It

gives good results but is expensive to install and makes an extremely complicated piping system.

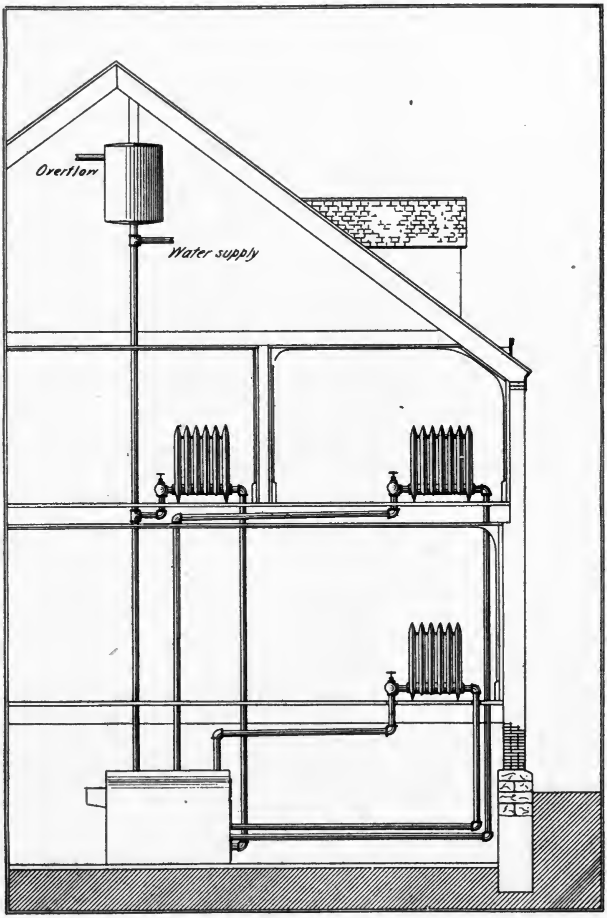


Fig. 52.

Overhead System.—The overhead system is shown in Fig. 53. In this system the flow main is carried

directly from the boiler to the highest point in the system, usually the attic. From this flow main risers ex-

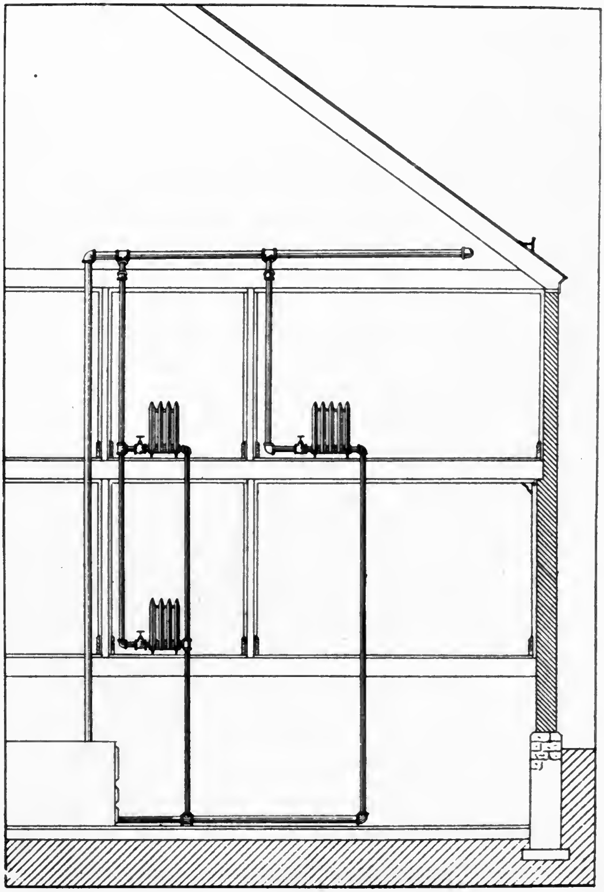


Fig. 53.

tend to the basement and connect to the main return. This system is sometimes modified as shown in Fig. 54.

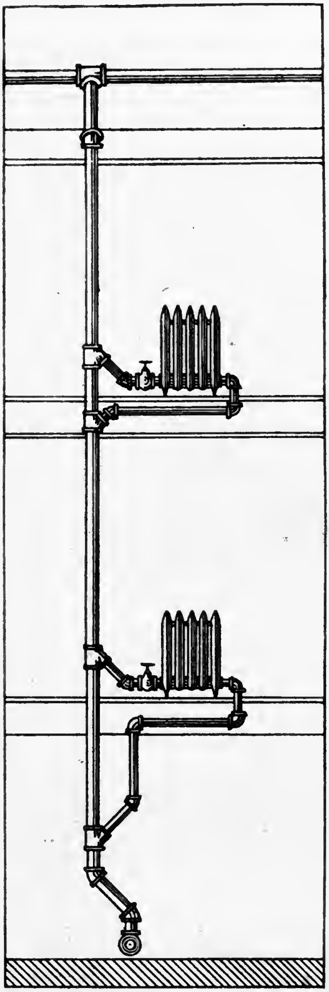


Fig. 54.

In this case the riser in both flow and return main to the radiator takes its supply at a point near the level of the radiator and delivers the water at a point below the level of the radiator in the same main. One objection to this arrangement is the fact that the radiators on the upper floor will be considerably warmer than the radiators on the lower floors and where this system is installed larger radiators should be used on the lower floors. It has the advantage of simplicity.

Open and Closed Circuits.—In the systems described, with the exception of Fig. 54, the circulation from flow to return main takes place through the radiators. This is what is termed an open circuit. In the open circuit system, where two or three radiators are closed of, the resistance to circulation is greatly increased and the system will be slow to circulate when the radiators are opened. This may be avoided by con-

necting up the piping system as shown in Fig. 55. The closed circuit system is particularly desirable in large buildings, especially buildings having very long horizontal mains.

Single Pipe System.—In this system the hot water main acts as both flow and return main, the radiators being connected on the two-pipe systems as shown in

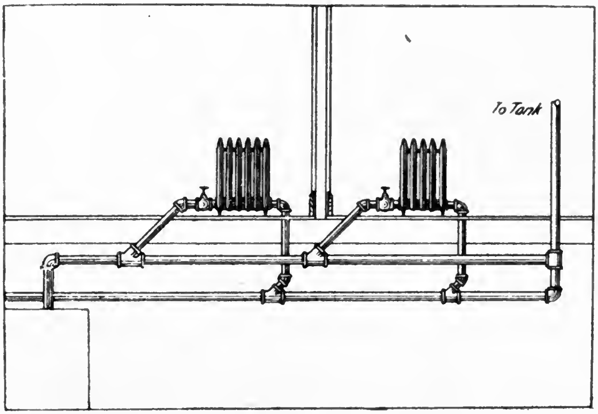


Fig. 55.

Fig. 56. It is necessary in the single-pipe hot water system to make the mains very large in diameter, as the current in them must be relatively slow. In this system the hot water passes along the top of the main and the cold water passes along the bottom of the main. It is necessary, then, that the flow riser going to the radiator be connected to the top of the main and the return riser coming from the radiator be connected to the bottom of the main. The main itself is usually installed on a closed circuit, as shown in Fig. 56. The single-pipe

system of distribution has not been extensively used and has not great advantage over the standard system of piping.

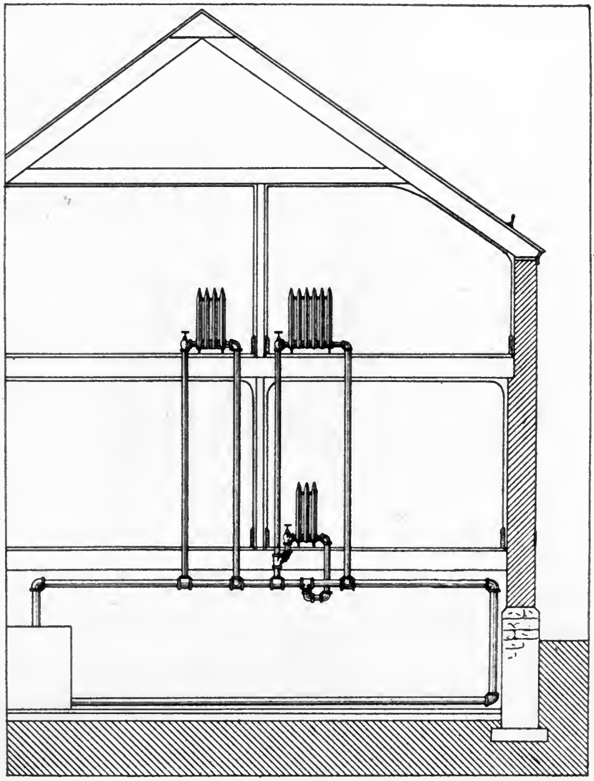


Fig. 56.

Velocity of Flow.—As previously stated, the hot water system should be so designed that the resistance of flow to each radiator should be proportional to the force producing flow. The water will always seek the

path of least resistance, so that the radiators having the smallest pipe resistance will receive the largest quantity of water, and radiators having the largest pipe resistance will be proportionally colder. A series of experiments have been made at the University of Michigan to determine the velocity of water in a hot water heating system under actual conditions of operation with full sized

TABLE XXXIV.—VELOCITY OF HOT WATER CIRCULATION (FEET PER SECOND).

Height of Circuit in Feet.	—Difference in Temperature.— 10.	15.	20.
5	.135	.39	.55
10	.19	.56	.78
15	.235	.69	.95
20	.27	.79	1.09
25	.30	.88	1.22
30	.31	.96	1.34
40	.38	1.11	1.53
50	.425	1.25	1.74

pipes and radiators. The actual velocity was found to vary from one-quarter to one-half of the theoretical velocity, depending upon the difference in temperature between the hot and cold leg of the system. In Table XXXIV the actual velocities have been computed from the results obtained by these experiments for different heights and different conditions of temperature.

Resistance of Pipe and Fittings.—No complete set of experiments has been made to determine the resistance of pipe and fittings. The University of Michigan at the present time is making a series of experiments, but these have not yet been completed. The following are the ordinary assumptions that have been made:

TABLE XXXV.—SIZE OF HOT WATER MAINS.

Diameter of mains.	——Total Length of Circuit in Feet.—— 50.	100.	200.	300.
1	40	30	..	..
1¼	60	45	30	..
1½	90	60	40	30
2	160	120	70	60
2½	250	200	120	110
3	350	300	200	190
3½	500	400	330	250
4	650	500	450	350
4½	900	700	650	500
5	1,200	1,000	800	650
6	1,500	1,200	1,200	1,000

Resistance of standard elbow=25 feet of pipe.
Resistance of standard tee=25 feet of pipe.
Resistance of standard return bend=35 feet of pipe.
Resistance of the ordinary radiator connection from the flow main through the radiator to the return main is equivalent to about 100 feet of pipe.

Size of Pipe.—The size of pipe may be figured by assuming the actual velocity due to the head and calculating the size required to carry a given amount of water. This is usually done in large buildings. In smaller buildings it is customary to follow the rules used in good practice.

TABLE XXXVI.

The capacity of mains 100 ft. long, expressed in the number of square feet of hot-water radiating surface they will supply, the radiators being placed in rooms at 70° Fahr., and 20° drop being assumed.

Diameter of Pipes. Inches.	Two pipe up Feed Open tank. Direct Radiation.	One pipe up Feed Open tank. Direct Radiation.	Overhead Open tank. Direct Radiation.	Overhead Closed Tank. Direct Radiation.	Two-Pipe Open tank. Indirect, 12 in. above boiler.
1¼	75	45	127	250	48
1½	107	65	181	335	69
2	200	121	339	667	129
2½	314	190	533	1,060	202
3	540	328	916	1,800	348
3½	780	474	1,334	2,600	502
4	1,060	645	1,800	3,350	684
5	1,860	1,130	3,150	6,200	1,200
6	2,960	1,800	5,000	9,800	1,910
7	4,280	2,700	7,200	13,900	2,760
8	5,850	3,500	9,900	19,500	3,778

Table XXXV gives the pipe sizes of the mains to supply different quantities of direct radiation at different distances from the boiler. In establishing the size of the risers it is customary to start with a riser the same size as the radiator connection and carry the riser down to the floor below where the next radiator connects. If the radiator does not exceed 60 feet in size, add one pipe size to the pipe.

Table XXXVI gives the radiation that may be carried by different sized pipes in the different systems.

Table XXXVII gives the size of risers for various quantities of radiation on different stories.

TABLE XXXVII.

The capacity of risers expressed in the number of square feet of direct hot water radiating surface, they will supply the radiators being placed in room at 70° Fahr. and 20° drop being assumed:

Diameter of Riser	Open Tank System.				Closed Tank Overhead System.
Inches.	First Floor.	Second Floor.	Third Floor.	Fourth Floor.	Drop risers, not exceeding 4 floors.
1	33	46	57	64	48
1¼	71	104	124	142	112
1½	100	140	175	200	160
2	187	262	325	375	300
2½	292	410	492	580	471
3	500	755	875	1,000	810

The following are radiator tappings for hot water radiators:

Radiators containing 40 sq. ft. and under........1 inch
Radiators containing above 40 sq. ft. and not exceeding 72 sq. ft..............................1¼ inch
Radiators containing above 72 sq ft...........1½ inch

Air Valves, Pitch and Support of Pipes.—Hot water piping should be pitched towards the boiler so that the water may be drained out of the system at the boiler and arrangements should be made so that the water can be drained to the sewer. This is necessary on account of freezing if the plant is not kept in operation. The piping should be supported the same as for steam pipes, with supports about every 10 feet. Care should be taken that the pipes are straight, as any sudden elevation in the pipe will form a pocket in which air will collect, and this collecting of air in the pocket will prevent the flow of water. An accumulation of air in the pipe will stop the circulation almost as effectively as a valve. The expan-

sion of pipes by heat must also be taken care of as in the steam system. All branches going from the piping system and supplying radiators below the level of the mains should come off the bottom of the main, so as to prevent air accumulating and sealing the pipe.

All radiators and high points in the mains where air will collect should be provided with air valves.

There are special air valves made for hot water work. These will be described later.

CHAPTER IX.

VENTILATION.

Necessity of Ventilation.—The necessity of ventilation, that is, of renewing the air in a closed room, is due, first to the vitiation of the air by the products of respiration from the persons in the room; second, to the products of combustion from artificial illumination; third, to the heat generated by persons and lights in the room; and, fourth, to the presence of gases from chemical processes.

In a small house or a small school building ventilation is very easily produced by methods which employ natural draft, such at hot air furnaces, steam and indirect radiators. In all systems using natural draft, the force of the draft depends upon the difference of the temperature between the air inside and that outside the flue. Where this difference amounts to only 30° or 40° the difference in the weights of the columns of air is so small that the force producing draft is very light and may be easily overcome by external conditions. In larger buildings it is not possible to use natural draft as the flues become excessive in size and are not certain enough in their operation. This has led to the use in school buildings and other public buildings of a forced system of ventilation in which the circulation is produced by a fan or system of fans.

The perfectness of the ventilation in a room is ordinarily determined by the amount of carbonic acid gas. Carbonic acid gas is not poisonous in itself. Its injurious effects are produced entirely by the reduction of the oxygen in the room. There are, however, other in-

jurious gases given off from the body, together with the carbonic acid gas.

Products of Respiration.—The lungs take in oxygen from the air, which combines with the tissues of the body, forming the products of combustion which are given off by the excretory organs—lungs, skin, etc. The principal excretions removed by the lungs are carbonic acid gas, water vapor mixed with other gases and some animal matter. These excretions, together with excretions from the skin, produce a disagreeable odor and may be poisonous. The average man when sitting still consumes in breathing from 19 to 25 cubic feet of air per hour, and when exercising from 26 to 35 cubic feet per hour. The amount of carbon dioxide and water vapor given off per hour by human beings is given in Table XXXVIII.

TABLE XXXVIII.—AIR POLLUTION TESTS.

Subject to Test.	At Work.				At Rest.			
	Temp. Deg.F.	Humid. P.C.	CO2 Cu.Ft.	H2O Grains.	Temp. Deg.F.	Humid. P.C.	CO2 Cu.Ft.	H2O Grains.
Laborer	45	81	1.515	2.03	69	20	.551	1.12
Laborer	77	47	1.423	8.05	78	26	.586	2.55
Clerk	64	44	1.331	1.768	69	29	1.141	1.19
Draughtsman	69	41	1.61	1.61	..	..	...	....
Average man	..	..	....	....	66	63	.412	1,365
Woman	..	..	.600	....	..	..	...	....
Boy	..	..	.48	....	..	..	...	....
Girl	..	..	.39	....	..	..	...	....

Products of Combustion.—The products of combustion from the sources of heating, such as grates, stoves, etc., are drawn off by the chimney, but the products of combustion from the lights in a room pass directly into the room. Lights give off carbonic acid gas, watery vapor, and traces of sulphuric acid. Table XXXIX gives the consumption of combustibles and the generation of carbon acid gas by ordinary forms of lighting. The table is given for each normal candle power.

TABLE XXXIX.—POLLUTION BY LIGHTING.

Source.	Consumption of Combustible per C. P. in Cu. Ft Per Hour.	Carbonic Acid per C. P. in Cu. Ft. Per Hour.
Gas—Fishtail burner	.802—.527	.494—.304
Gas—Argand burner	.0 —.445	.254
Gas—Welsbach burner	.053—.024	.030—.057
Petroleum, round burner....	Gals. .00050	.112
Petroleum, small flat burner.	Gals. .00198	.335
Wax candles	Oz. .271	.417
Paraffine candle	Oz. .324	.459

Chemical Processes.—The products of chemical operations should never accumulate in a room so that the odor is perceptible. In some industrial processes it is almost impossible to avoid a certain amount of concentration of the gases. In such a case the chemical products should be sufficiently diluted with fresh air so as not to produce injurious effects upon the occupants of the room.

Table XL gives the relative dilution required for different gases in cubic feet per 100 cubic feet of air.

TABLE XL.—AIR DILUTION.

	Detrimental Effect Occurs in Several Hrs.	in ½-1 Hr.
Iodine vapors	.00005	.0003
Chlorine or bromide vapors...............	.0001	.0004
Muriatic acid	.001	.005
Sulphuric acid	...	.005
Sulphureted hydrogen	...	.02
Ammonia	.01	.03
Carbonic Oxide	.02	.05
Carbonic acid	1.00	8.00
Carbureted hydrogen	...	6.56 gr.

Generation of Heat by Human Beings.—The amount of heat generated by a human being varies with age, activity and temperature of the surrounding air. The average amount of heat given off by an adult is about 400 B. t. u. per hour, and by a child about half that amount, or 200 B. t. u. per hour. Of 400 B. t. u. given off by human beings about 30 per cent is lost by contact of air and about 43 per cent by radiation, the balance is lost by exhalation and other losses.

Comparing this with the average steam radiator, we see that a child is equal to about eight-tenths of a square foot of radiation and an adult man is equal to about one and eight-tenths of a square foot of radiation. This becomes a very important point in the heating of large halls, particularly if they are very crowded and have very little external wall space, as the heat given off by the persons in the room may be more than sufficient to warm the room, which will necessitate providing for the removal of this heat from the room.

Generation of Heat by Illumination.—Ordinarily the heat given off by electric lights is so small as to be negligible, but where oil lamps, candles, or gas lights are used, the heat given off is appreciable, except in the case of the Welsbach burner, which gives off relatively a small amount of heat. The ordinary fish-tail burner is equal to about one and four-tenths square feet of radiation.

Table XLI gives the heat generated by different sources of illumination per candle power per hour.

TABLE XLI.—HEAT GIVEN OFF BY ILLUMINANTS.

Source.	Total B. T. U.'s Given Off.
Gas—Fishtail burner	313
Gas—Argand burner	198
Gas—Welsbach burner	32
Petroleum	158
Incandescent lamp	14
Arc lamp	2.5

Changes of Air Necessary.—In order that the air in a room occupied by human beings may be reasonably pure it should be diluted with fresh air. The amount of the dilution, except where chemical processes are to be considered, is usually determined by the per cent of carbon dioxide present, which is assumed to be proportional to the products of respiration. The carbon dioxide itself

is not injurious, but it serves as an indication of the presence of other injurious substances. It is usually assumed that carbon dioxide is uniformly distributed throughout the room. This, however, is not strictly true, as carbon dioxide is a very heavy gas and naturally accumulates at the floor. Air that contains more than ten parts of carbon dioxide to each 10,000 parts of air produced by exhalation is of an unhealthful quality. Seven parts in 10,000 is ordinarily considered the minimum limit of ventilation. The effects of poor ventilation are usually shown when the carbon dioxide exceeds six parts in 10,000 parts. The following rule may be used to determine the necessary amount of air that should be supplied to a room: Multiply the number of sources of carbon dioxide by the amount of carbon dioxide given off from each source. Multiply the result by 10,000 and divide by 4. This will give the minimum amount of ventilation to be allowed per person. For satisfactory ventilation divide by 3. Pure air is found to contain about 3 parts of carbon dioxide in 10,000.

This may be expressed as follows:

Let S=cu. ft. carbonic acid from each source per hour.
n=number of sources.
a—allowable limit of CO_2 in 10,000 cu. ft. of air.
A=the cu. ft. of air to be supplied.

$$\text{Then } A=10{,}000\,\frac{n\,S}{a-4}$$

a should not exceed 7 and *a* equals 10 is the sanitary limit.

For example, take a hall containing 400 adults, giving off (from Table XXXVIII) .58 cu. ft. of CO_2 per hour.

Then to determine the amount of air necessary substitute in the above formula

$$A=10,000\,\frac{400\times .58}{6-3}\ \text{solving}$$

A=770,000 cu. ft. per hour.

Ordinary Assumption for Change of Air.—The amount of air necessary is usually determined by allowing each person in the room so many cubic feet of air per hour. The changes of air ordinarily allowed are given in Table XLII.

TABLE XLII.—CHANGE OF AIR NECESSSARY.

Hospitals	3,600 cu. ft. per person
Barracks and workshops	3,000 cu. ft. per person
Schools	2,400 cu. ft. per person
Churches, theaters and audience halls	2,000 cu. ft. per seat
Office rooms	1,800 cu. ft.
Toilet and bath rooms	2,400 cu. ft. per fixture
Dining rooms	1,800 cu. ft. per person

These figures in the above table give sufficient air so that the air in the room will remain continuously pure, even though occupied all the time. When less than these amounts are used there is danger, if the buildings are very tight, that the rooms may become foul. The figures given above are seldom realized in practice, except where the fan system of ventilation is used. In school buildings using an indirect system the amount of air allowed per child seldom exceeds 1,000 cubic feet of air per hour.

Another method that is sometimes used in figuring ventilation, particularly for smaller buildings, is to allow so many changes of air per hour. In rooms seldom occupied allow the air to be changed about once per hour. In living rooms about one and a half to two times per hour. In toilet rooms four to five times per hour. In restaurants, where smoking is allowed, from five to

six times per hour. In extreme cases the change of air is sometimes as high as ten times per hour. It is difficult, however, to change the air in a room very rapidly without producing drafts.

Effects of Poor Ventilation.—The effects of poor ventilation have been frequently tested in schools where for a short time the ventilation has been cut off. The pupils at first complain of being cold, and it is found necessary to raise the temperature of the room from 70° to 80° before the occupants of the room are warm. This is no doubt due to the reduction in vitality owing to the impurity of the air, and a lack of oxygen in the lungs. After the ventilation has been cut off for a period of from 20 to 30 minutes, the pupils begin to complain of headache. If the ventilation is cut off much longer it is necessary to dismiss some pupils on account of headache.

Systems of Ventilation.—For small residences and small buildings where it is not possible to go to any great expense for an elaborate system of ventilation, the best form of heating giving adequate ventilation is the hot air furnace. In large houses where it is not possible to apply the hot air system, the best system is indrect radiators, either steam or hot water. In still larger buildings where the flues have a large resistance and it is necessary to supply air in large quantities, the only feasible system of distributing air is by mechanical means. The usual system employed is to draw the air through a series of steam coils into a tempered air chamber. In this chamber are located the fans. The fan or fans deliver the air through heating coils into the building. Systems similar to this

have been used where the coils have been replaced by hot air furnaces.

Systems of ventilation using mechanical draft give very satisfactory results if properly installed and allow of great latitude in the arrangement of the plant. Before taking up the details of the systems of ventilation it is well to consider certain fundamental facts in the science of ventilation.

Air Inlets and Outlets.—The arrangement of inlet and outlet registers in a room should be given very

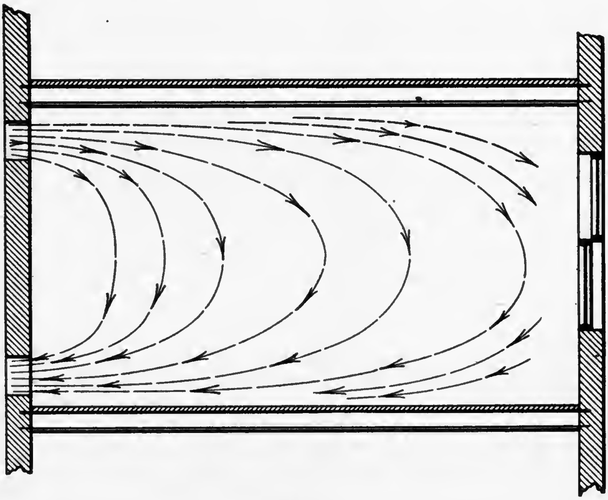


Fig. 57.

careful consideration. They should be so placed as to avoid drafts and to insure uniform circulation throughout the room. Their position should be such that the air cannot pass directly from inlet to outlet flue. The creation of drafts may be avoided by bringing the air in at very low velocities, particularly where the air

enters so as to strike the occupants of the room. The velocity passing through the registers should not exceed 300 feet per minute; if it is admitted just over the heads and where the current of air strikes a person, it should not exceed 150 feet per minute. Where the air is brought in so that it cannot strike the occupants of the room the velocity of air through the registers may be as high as 400 feet per minute.

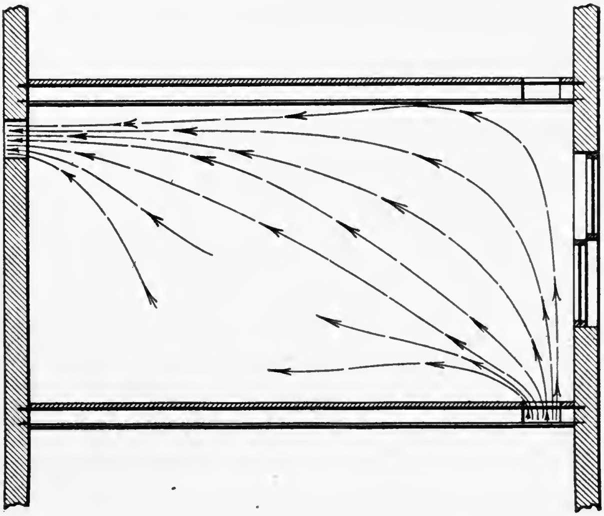


Fig. 58.

The most satisfactory arrangement for most rooms is shown in Fig. 57. In this figure the inlet register is shown near the ceiling. The hot air leaving this register rises to the ceiling, passes along the ceiling to the cold window surfaces, where it is cooled and drops to the floor; passes along the floor and out the vent flue. The inlet register is usually located about 8 feet above

the floor and the outlet register from 4 to 6 inches above the floor, just sufficient to avoid dust and dirt being swept into it. Where the current of air leaving the inlet register is liable to be centered in one point in the room it is well to put a diffusing register on the air inlet so that the air will be distributed in a number

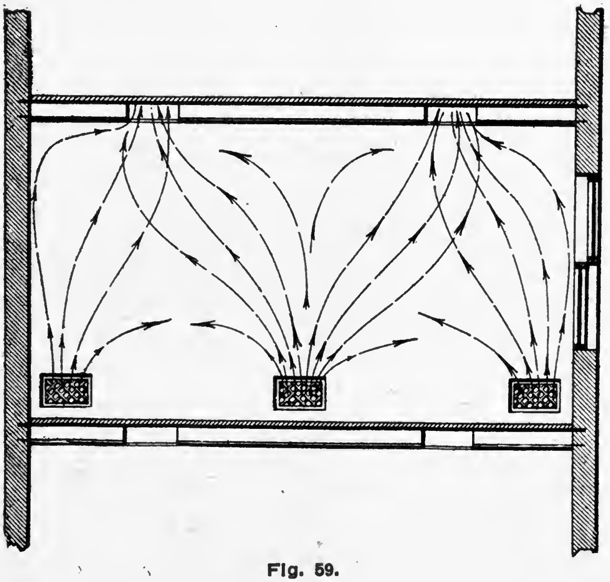


Fig. 59.

of streams in different directons throughout the room. This arrangement of inlet and outlet registers is the usual one for school buildings. It is preferable to have the inlet and outlet register on the inside walls opposite the window surfaces and both registers on the same wall. This, however, is not absolutely necessary. The inlet and outlet registers should never be on the outside walls. Where the inlet register is placed on the floor

and the outlet register at the ceiling then the air coming from the inlet register will pass directly to the outlet register and a large proportion of the heated air be lost; in addition there will be very little circulation of air in the room, as shown in Fig. 58.

In rooms for restaurant purposes, where smoking is allowed or in smoking rooms or in kitchens, the air must be taken off the ceiling, as the foul air, being warmer, rises to the ceiling. In this case it is necessary to bring the ventilating air in at the baseboard, at a very low velocity and at a number of places and take the air out at definite points near the ceiling, as shown in Fig. 59. In theaters and churches special means must be employed for securing ventilation. It is customary to admit the air in a large number of places. Sometimes this is done by means of a large number of small registers placed directly under the seats. Care, however, must be used in doing this to avoid drafts. Another method is to employ a large number of openings around the sides of the room. The air is usually taken off near the stage at the lowest point in the auditorium. There should be provided in all auditoriums some means of taking the air off the ceiling, as oftentimes the heat given off by the occupants of the room is more than sufficient to heat the room, and in addition we have the heat given off by the sources of illumination. This heat can be best taken care of at the ceiling line, which is naturally the warmest point in the room.

CHAPTER X.

DESIGN OF HOT AIR HEATING SYSTEM.

Design of Hot Air System.—In a hot air furnace the cold air from the outside is passed over heated iron surfaces, usually enclosed in galvanized iron or brick walls. The space between the walls and hot surfaces of the furnace is connected to the outside air at the bottom and at the top to the flues leading to the rooms. The amount of air circulating through the furnace will depend upon the temperature of the hot air leaving the furnace and the height and resistance of the flues. In order that the air in a room may be quickly replaced by warm air it is necessary that the room be provided with a foul air flue.

A great many of the difficulties that have been experienced with the hot air system as ordinarily installed are due to the sharp competition in business, which has resulted in the erection of plants of inferior workmanship and design. One of the commonest mistakes is the installation of a furnace much too small to do the work properly. The result of putting in a small furnace is that the fire must be continually crowded so that the heating surface is at high temperature and a large amount of the heat of the coal is wasted in excessive stack temperature.

The hot air system with natural draft should not be used in houses where the horizontal portion of the hot air flues would exceed 20 feet in length. In very large houses two or more furnaces may be used to avoid excessive pipe resistance.

Hot Air Furnaces.—Hot air furnaces are as varied in types as are steam boilers. They are made either of cast iron or steel. It is difficult to decide between the merits of these two materials. Cast iron is less liable to be rapidly deteriorated by rust when the boiler stands in the summer, but it is more easily broken either by misuse or shrinkage strains in the castings. There is no essential difference between the metals in their conducting capacity as applied in these furnaces.

It is very important to see that the furnace is so constructed that the joints between the fire-box and hot-air chamber are tight, so that the air entering the rooms may not be mixed with gases of combustion. This is one of the most difficult things to prevent in the hot air furnace. Joints should be as few as possible and vertical joints should be avoided. The introduction of moisture into the air passing through the furnace is an important consideration and will be treated in a separate paragraph.

The builders rate their furnaces at about their maximum capacity. The rating being expressed as the number of cubic feet of building volume the furnace will heat. In selecting a furnace it is wise to have 25 to 50 per cent excess capacity in the furnace over the builder's rating.

The fire pot of a furnace should be slightly conical in shape and should be large enough to contain sufficient fuel to last eight hours. The rate of combustion on the grate should be taken at not to exceed 4 pounds of coal per hour. A high temperature of combustion is usually desirable for the best economy, but the stack gases should not exceed 500°.

The air space between the furnace and the outside

casing should have at least 25 per cent more cross-sectional area than the leader pipes taken from it. A furnace should be proportioned so that the air leaving it should not exceed 180° in temperature.

There should be one square foot of grate for every 30 to 50 square feet of heating surface in the furnace. Each square foot of heating surface may be assumed to give off 1,000 to 1,500 B. t. u. per hour.

A furnace should be provided with some form of shaking and dumping grate which is easily cleaned. In addition to draft doors admitting air below the grates, the furnace is usually provided with a check damper in the smoke pipe. The draft door and check damper are arranged so that they may be controlled by chains situated in some convenient point in the room above.

Necessity of Supplying Moisture to Heated Air.— It is very important that air after being heated by the furnace pass over the surface of a pan of water so that it can take up moisture. One pound of air at 32° F. will hold in the form of a vapor .003 of a pound of water, and at 150 degrees it will hold .22, or about 70 times as much. If then we take air saturated with moisture at an outside temperature of 32 degrees and heat it up to 150 degrees we have increased its capacity for moisture 70 times. On entering the rooms if the air has not been given opportunity to take up moisture it will take it up from the objects of the room. This drying effect of the air injures the furniture and woodwork and affects the persons occupying the room, producing a dry throat and a feeling of cold due to rapid evaporation from the skin.

The usual method of overcoming this is to have a pan

filled with water situated in the furnace near the fire-box. This, however, is the wrong end of the furnace to place the pan, as the air entering is coolest at this point. The water should be added to the air as it leaves the furnace. In some hot air installations every pipe leaving the furnace has a trough in it, which is filled with water, and from this water the air takes up its moisture.

Cold Air Duct.—The cold air supplied to the furnace is usually taken from one of the basement windows and brought to the furnace through a tile or wooden duct lined with galvanized iron; where a tile duct is used it is placed below the level of the cellar floor. The cold air should be taken from the side of the house that is subject to the prevailing winds. It is sometimes desirable to have cold air ducts leading to different sides of the house, so that the supply of cold air may be taken from the windiest side. The cross-section of the cold air duct should be 80 per cent of the area of the hot air leaders leaving the furnace.

It is well to provide some means of recirculation of the air in the house through the furnace. The air for recirculation is usually taken from the Hall. If it is desired to recirculate partially and take the balance of the air from outside, the recirculating pipe should be brought to the furnace separately, and a deflecting plate placed in the air space under the furnace. If this is not done the air will come in from the outside and may pass up the recirculating pipe instead of going to the furnace. If, however, the recirculating pipe is only to be used when the cold air pipe from outside is closed, then the recirculating pipe can be conducted into the cold air

pipe directly. In this case the cold air pipe and recirculating pipe must both be provided with dampers. The cold air pipe should have at least three-fourths of the combined areas of the hot air pipes.

It is a common error to make the recirculating pipe of a furnace system too small. The recirculating pipe should be not less than three-fourths the area of the cold air pipe. It is better to have it equal in area to the cold air pipe.

Hot Air Leaders and Flues.—The furnace should be centrally located, or if the coldest winds come from a certain direction, it can be located more on that side of the house from which the cold winds come. The hot air flues leading from the furnace should be as short and direct as possible; long horizontal pipes should be avoided. Horizontal pipes should pitch sharply towards the furnace, three-quarter inch to the foot is good practice. All hot air pipes should have nearly equal resistance to the passage of the air. The hot air flues should have as few and as easy turns as possible. They should never be placed in the outside walls. Uptake flues of any kind in outside walls seldom draw satisfactorily. The hot air flue should enter the room in most cases opposite the largest exposed glass surface or some distance from it. The circulation of air in the room would be best if the hot air entered near the ceiling. The principal objection to this is that the register in the wall is apt to blacken the wall and it does not allow people to warm themselves over it. Floor registers are very objectionable as they always serve as receptacles for all kinds of rubbish and sweepings.

Dampers should be provided in all pipes leading to

rooms above the first floor. If all the registers are provided with dampers there is danger of burning the furnace, due to shutting off all the passages for removing hot air and preventing circulation in the furnace. It is good practice to have no valve in the hall register so one pipe will always be open.

Proportions of Hot Air Flues.—The velocity of air for first floor leaders may be calculated as three or four feet per second, second floor four to five feet per second, third floor and floors above five to six feet per second. The flues leading to the second and third floor room may have a velocity as high as 400 feet per minute.

In the best installations the leads and flues are double walled with asbestos between the walls. The cross-sectional area of all the leaders should be from 1.1 to 1.5 times the area of the grate.

The registers should be proportioned so as to give a velocity of two to three feet per second on the first floor and three to four feet per second on the floors above. The effective area of the ordinary registers is about 50 per cent of the actual area, taking outside dimensions.

H. B. Carpenter, in a paper before the Society of Heating and Ventilating Engineers (Transactions, vol. 5, p. 77), gives the following rule for finding the cubic feet of air passing through pipes per minute:

To the first floor multiply the area in inches by 1.25.

To the second floor multiply the area in inches by 1.66.

To the third floor multiply the area in inches by 2.08.

It is good practice to figure on changing the air in the principal rooms five times per hour in hot air heating.

Foul Air Flues.—The foul air flues should be placed

in the inside walls and with foul air registers at the baseboard. The reason being that the hot air entering the room opposite the window surfaces rises to the ceiling, passes along the ceiling to the windows and is cooled. It then drops to the floor line, passes along the floor and out the foul air register. The hot air register should be a sufficient distance from the foul air register so that the hot air will not pass directly to the foul air flue. A cheap foul air flue can be made by having a register in the baseboard opening into the spaces between the studs, selecting a space that is open to the attic, a ventilator is placed on the attic space and discharges foul air out of doors. No two rooms should open into the same studding space. A still better draft can be produced by extending each flue separately by galvanized iron pipe to the ventilator. If no ventilating flues are provided, it is very difficult, especially if the house is tight, to get a proper circulation of hot air from the furnace; you cannot put hot air into a room if there is no provision for taking cold air out.

The area of these foul air flues should be not less than 80 per cent of that of the warm air flues and they are often made equal in area to the area of the warm air flues.

A fireplace makes one of the best forms of foul air flue. In a house well provided with fireplaces, it is often not necessary to provide any other foul air flues.

General Proportions of Hot Air Systems.—The size of the hot air flue, vent flue, hot air register, heating surface and grate surface in the furnace is given in Table XLII. This table is given for rooms of average proportion and under average conditions.

TABLE XLIII.—PROPORTIONS OF HOT AIR HEATING SYSTEM.

Contents of Room in Cubic Feet.	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	5,000	6,000	8,000	10,000
First Floor—												
Diameter hot air flue, in.	6	8	9	10	11	12	13	14	16	17	20	24
Diameter foul air flue, in.	6	8	9	10	11	12	13	14	16	17	20	24
Second Floor—												
Diameter hot air flue, in.	6	7	8	9	10	11	11	12	14	15	18	20
Diameter foul air flue, in.	6	7	8	8	9	9	10	10	12	12	14	16
Grate area in furnace, sq. in.	25	50	75	100	125	150	175	200	250	300	350	400
Heating surface in furnace, sq. ft.	5	10	15	20	25	30	35	40	50	62.5	80	100

The following assumptions have been made the above table: Temperature outside air, 0 degree; temperature of air in the room, 70 degrees; changes of air in the room, three times per hour.

Velocity of air in hot air flues, 1st floor, 3 ft. per second.

Velocity of air in hot air flues, 2nd floor, 4 ft. per second.

Velocity of air in four air flues, 1st and 2nd floors, 3 ft. per second.

Temperature of air entering the room, 160 degrees.

Proportion of grate surface to heating surface, 1 to 30.

Pounds of coal burned per square foot of grate surface per hour, 3.

Suggestions for Operating Hot Air Furnaces.—The temperature of the rooms should be regulated by the drafts of the furnace as much as possible. The heating surfaces of the furnace should never be brought to a red heat. If it is necessary to do this to keep the rooms warm, the furnace is too small.

Ashes should be frequently removed from the furnace, as an accumulation of ashes may burn out the grate. Never shake the fire more than is necessary to expose

the red coals to the ash pit. The furnace should be cleaned at least once a year. The water pan of the furnace should be kept full of water.

ROUGH RULES FOR HOT AIR SYSTEM.

1. The volume of the house divided by 50 equals square feet of heating surface in furnace radiator.

2. The volume of the house divided by 20 equals the number of square inches of grate area in the furnace.

3. Divide the volume of the room by 20 and the square root of the quotient will be the diameter of the furnace pipe for the first floor room. For second floor rooms divide the volume by 25 and the square root of the quotient will be the diameter of the furnace pipe.

Example of Hot Air System.—As an example of the hot air system applied to the ordinary dwelling, take the same house that was used as an example of direct steam heating. The heat lost from the rooms would be the same as in the case of direct steam. As an example of an individual room take the parlor.

From Table XX we see that the volume of the parlor is 1,665 cubic feet and the heat lost 10,395 B. t. u. per hour. In figuring the heating system for the parlor the following assumption will be made: The hot air enters the room at 160°. Cold air enters the furnace at 0°. The temperature in the room is 70°. Then the air entering the room is reduced in temperature 160—70=90°. Each pounds of air on having its temperature reduced 90° would give up .2375×90=21.4 B. t. u. Then there will have to be introduced into the room to supply heat lost from the room 10,395÷21.4=485 pounds of air per hour. At atmospheric pressure a pound of

air occupies approximately 13 cubic feet, hence 485 pounds of air is equal to 6,300 cubic feet. This is the amount of air which must be delivered to the room per hour; 6,300 cubic feet of air per hour is equal to 1.75 cubic feet per second. Allowing a velocity of 3 feet per second, the area of the pipe would be $1.75 \div 3 = .58$ square feet, which is equivalent to 84 square inches, or approximately the area of a pipe 10.5 inches in diameter. To warm the air going to the parlor would require $485 \times .2375 \times 160 = 18{,}500$ B. t. u. In a similar way the same quantities have been calculated for the other rooms. Except that for the second floor room, a velocity of 4 feet per second has been allowed.

TABLE XLIV.

	Volume of room.	B.t.u. lost. from room per hour.	B.t.u. given air per hour.	Cu. ft. of air entering room.	Diameter of hot air pipe.
First Floor.					
Parlor	1,665	10,395	18,500	6,300	10½
Sitting room	2,100	7,035	12,500	4,350	9
Dining room	1,640	7,350	12,800	4,500	9
Kitchen	1,610	10,300	18,000	6,250	10½
Hall	1,210	7,035	12,500	4,350	9
Second Floor.					
West Alcove	1,320	10,050	17,900	6,200	9
Alcove	810	7,560	13,400	4,750	8
South chamber	1,560	7,035	12,500	4,400	8
North chamber	1,440	7,455	13,300	4,650	8
Bath	410	3,150	5,600	1,850	6
East chamber	880	5,250	9,400	3,300	7
Halls	88	2,730	4,800	1,750	6
			151,200		

Column 3 of Table XLIV shows the heat which is left by the air in the room. Column 4 shows the heat used to warm the air entering the room. The difference between these two columns is the heat lost up the ventilating flues. This loss should not be charged against the hot air furnace, but should be considered as the loss that must be charged to ventilation. The loss is about 44 per cent if the temperature of the outside air is at 0°

and the temperature of the air entering the room is 160°. As the temperature of the outside air or the incoming air is increased proportionately more heat enters the room and this loss becomes less. During the average winter weather the outside air is 35°, in which case the per cent of loss by ventilation, that is, through the ventilating flues, is about 30 per cent.

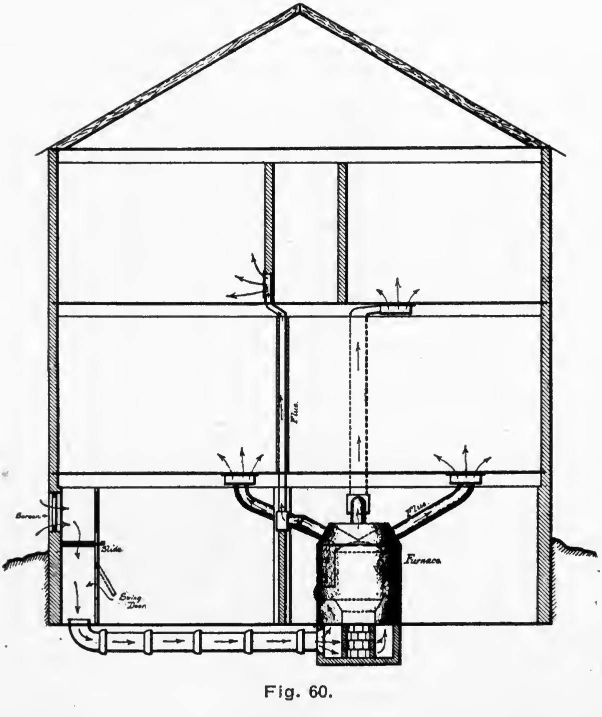


Fig. 60.

Summing up column 4 of the table gives the heat required to warm the air entering the entire house in zero weather or 151,200 B. t. u. If we assume that 80

per cent of the coal goes into the heated air, then there will be required from the coal 151,200÷.8=188,500 B. t. u. per hour. A good anthracite coal contains about 13,500 B. t. u.; then in zero weather this house would use 188,500÷13,500=14 pounds of coal per hour. As the average loss from a house during the heating season is approximately 50 per cent of the loss during zero weather, the average consumption of coal in this house for the heating season would be 14×.5=7.00 pounds of coal per hour. Assuming the furnace to be operated 24 hours per day and 200 days per year, the coal consumption for this house would be 7×24×200÷2,000=16.8 tons. Fig. 60 shows a cross section of a house with the hot air system installed.

CHAPTER XI.

FAN SYSTEM OF HEATING.

Where it is necessary to introduce large quantities of air into a building for the purpose of ventilation a natural system of circulation is out of the question and it is necessary to force the air into the building by some mechanical device. This is usually done by means of a steel plate blower which delivers the air with sufficient pressure to force the air into all rooms in the building. The pressure required in the average building does not usually exceed one-quarter ounce. The mechanical system of ventilation has the additional advantage that its operation is entirely independent of the heating of the building and the building may be ventilated as easily in the summer as in the winter. The natural system of ventilation depends entirely upon the air in the flues being heated, and during the summer periods the system is inoperative.

Systems of Fan Heating.—There are two general schemes of fan heating, one in which the air is heated to a temperature higher than that in the room, so that it furnishes enough heat to supply the heat lost from the walls and windows, as well as to furnish air for ventilation. In the other system the heat loss from walls and windows is supplied by direct radiation situated in the room and the fan supplies only the necessary amount of air for ventilation. In the latter system the air for ventilation is supplied at about the temperature to be maintained in the room. The first system, in which all the heat is supplied by means of a fan, is most applica-

ble in buildings that must be heated and ventilated both night and day. Hospitals and asylums are buildings of this class. It has certain disadvantages, however. When a room has very large glass surfaces it is almost impossible with this system to prevent strong cold drafts coming down along the window surfaces. The system is in many cases wasteful. In order to heat a building it is often necessary to admit more air than is required for the purpose of ventilation, and all the heat put into the air to raise the temperature of the outside air to the temperature of the room is lost. On the other hand, this system requires but one system of heating, which makes it less expensive to install.

The second system mentioned, where direct radiation and a fan are both used, is most applicable in buildings that require ventilation only part of the time. Schools, factories, office buildings are buildings that may be included in this class. While the buildings are filled with occupants the fan system is operated; as soon as the occupants leave the building the fan system is closed and the building kept warm by means of direct radiation. The building is thus kept warm at a minimum expenditure for fuel. There is no necessity of introducing into the building more air than is necessary for ventilation. But the system is expensive to install, as it involves installing two separate systems of heating. This system is being more and more favorably considered, however, in connection with the class of buildings mentioned.

General Arrangement of the Fan System.—The usual arrangement of the fan system is shown in Fig. 61. The air is drawn first through a series of tempering coils

shown at A. Then it enters a tempered air chamber in which is located the fan. This delivers the air through a series of heating coils B into the hot air chamber. From this hot air chamber the individual rooms in the buildings take their heat. The tempered coils are usually designed to heat the air to about 70°. The fan takes this air at 70° and passes it to the heating coils. After leaving the heating coils the temperature of the air is from 130° to 140°. Where the air is used for ventilation only the heating coils are omitted and the air is deliv-

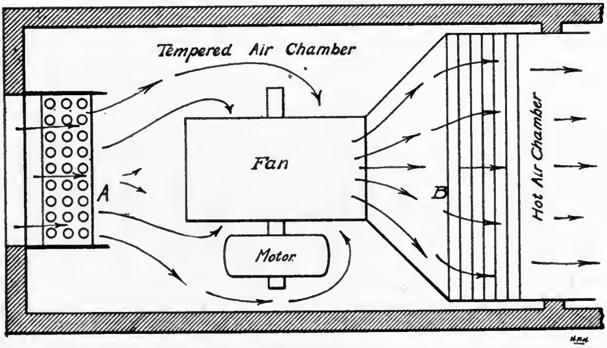


Fig. 61.

ered by the fan from the tempered air chamber directly to the room.

Quantity of Air to Be Supplied.—The quantity of air to be supplied to each room will depend upon the system of heating employed. If the heating is done entirely by fan enough air must be admitted so that the heat left by the air will be sufficient to heat the room. In audience and school rooms the amount of air necessary to supply proper ventilation is usually sufficient for heating. In offices and living rooms more air will have to

be supplied in order to heat the room than would be necessary for purposes of ventilation. Roughly speaking, if the number of cubic feet of air supplied to the room per hour is four times the cubic contents of the room the room will be heated, providing the air be supplied at not less than 140°. In a system where direct radiation is used to supply losses from walls and windows only enough air is introduced to supply the necessary ventilation. The amount of air necessary can be determined by rules previously given under the head of Ventilation.

Size, Speed and Horsepower of Fan.—In most cases the type of fan known as the steel plate blower or multivane fan is best adapted to the work of fan heating. The theory of this fan has been discussed by Weisbach and Lindner in their treatises, also by various writers in the Transaction of the Society of Heating and Ventilating Engineers. The results derived are difficult of application. The following general statement may be made, however: The discharge capacity of a fan depends upon the speed of the fan tips, the size of the fan blades, and the size of the discharge openings. As the discharge opening of the fan is decreased the velocity of the air leaving the fan increases and the pressure of air in the fan case increases until we get to the maximum pressure that can be produced by a certain velocity of fan tips. This will occur when the area of the outlet equals the effective area of the fan blades. This is the point at which the fan delivers the maximum amount of air corresponding to the pressure for a given speed. If we further reduce this discharge outlet the pressure in the fan case

remains constant, the quantity of air discharged is reduced and the power to drive the fan is reduced.

TABLE XLV.—FAN CAPACITIES.

Speeds, Capacities and Horse Powers of "A B C" Steel Plate Fans of Varying Revolutions.

R.P.M.	FAN	50	60	70	80	90	100	110	120	140	160	180	200	220	240
100	Per V.	785	942	1100	1257	1414	1571	1728	1885	2200	2513	2827	3141	3455	3769
	Air V.	685	820	957	1092	1230	1367	1503	1640	1915	2182	2459	2732	3005	3279
	Pres.	.017	.025	.034	.044	.055	.068	.082	.100	.134	.175	.231	.273	.335	.401
	Cu. Ft.	682	1121	1870	2652	3840	5475	6395	9565	14916	21750	30221	41608	55201	71941
	H. P.	.150	.222	.370	.476	.672	1.01	1.37	2.08	3.46	5.47	7.7	12.0	17.1	25.1
125	Per V.	981	1178	1375	1571	1768	1964	2160	2356	2750	3141	3533	3926	4318	4711
	Air V.	853	1025	1196	1366	1538	1707	1879	2029	2390	2724	3073	3415	3756	4098
	Pres.	.027	.039	.053	.060	.089	.106	.132	.153	.212	.276	.350	.435	.525	.626
	Cu. Ft.	852	1402	2338	3158	4809	6844	7992	11945	18645	27170	37767	52010	68997	99910
	H. P.	.175	.284	.439	.588	.934	1.34	2.06	2.90	5.00	8.15	12.5	19.3	29.2	43.5
150	Per V.	1177	1413	1650	1886	2121	2356	2592	2827	3300	3770	4240	4711	5182	5653
	Air V.	1025	1230	1432	1640	1845	2044	2255	2460	2870	3280	3688	4098	4500	4928
	Pres.	.039	.056	.075	.100	.120	.160	190	.230	.300	.400	.503	.626	.758	.904
	Cu. Ft.	1023	1681	2805	3979	5760	8110	9580	14360	22374	32610	45825	62412	82811	108120
	H. P.	.200	.325	.531	.756	1.27	1.86	2.74	3.90	7.22	11.3	19.6	32.1	46.2	68.6
175	Per V.	1374	1649	1925	2200	2474	2749	3024	3297	3850	4380	4947	5496	6046	6596
	Air V.	1195	1434	1674	1914	2152	2390	2630	2868	3350	3826	4303	4781	5260	5747
	Pres	.053	.076	.104	.134	.172	.212	.258	.306	.420	.554	.687	.848	1.02	1.21
	Cu. Ft.	1194	1962	3274	4622	6729	9594	11200	16715	26100	38043	52883	72814	96626	126089
	H. P.	.225	.393	.647	1.01	1.74	2.46	3.55	5.52	9.91	17.3	27.9	44.2	67.1	108.0
200	Per V.	1570	1884	2200	2511	2828	3142	3456	3770	4400	5026	5654	6282	6910	7538
	Air V.	1366	1640	1915	2187	2460	2737	3007	3280	3820	4375	4918	5465	6011	6558
	Pres.	.069	.101	.134	.175	.225	.274	.333	.392	.537	.700	.908	1.12	1.34	.159
	Cu. Ft.	1364	2242	3740	5304	7690	10960	12830	19150	29850	43520	60442	83231	110422	143902
	H. P.	.262	.478	.855	1.26	2.05	3.16	4.69	7.01	13.3	23.7	39.2	62.1	96.8	154.5
225	Per V.	1766	2120	2475	2829	3182	3534	3888	4241	4950	5654	6360	7065	7774	
	Air V.	1536	1844	2153	2459	2767	3073	3383	3688	4305	4919	5533	6148	6762	
	Pres.	.087	.126	.172	.225	.285	.351	.421	.507	.690	.901	1.14	1.41	1.69	
	Cu. Ft.	1534	2523	4207	5969	8655	12334	14385	21500	33560	48680	68000	99634	124217	
	H. P.	.300	.581	1.03	1.57	2.61	4.09	5.95	9.29	17.0	31.1	52.8	87.9	142.5	
250	Per V.	1963	2355	2750	3143	3535	3927	4320	4712	5500	6283	7067	7852		
	Air V.	1708	2048	2392	2734	3070	3416	3758	4100	4780	5450	6148	6840		
	Pres.	.109	.056	.213	.280	.360	.430	.520	.630	.860	1.12	1.48	1.73		
	Cu. Ft.	1706	2798	4675	6332	9600	13705	16000	23950	37310	54200	75558	104036		
	H. P.	.375	.684	1.22	1.79	3.32	4.97	7.44	11.6	22.5	41.2	71.7	121.4		
275	Per V.	2159	2591	3025	3457	3889	4319	4731	5183	6050	6911	7774			
	Air V.	1878	2258	2632	3008	3383	3755	4090	4507	5263	6018	6763			
	Pres.	.131	.189	.258	.337	.426	.526	.623	.756	1.04	1.35	1.71			
	Cu. Ft.	1876	3089	5142	7294	10578	15773	17394	26278	41020	58328	83104			
	H. P.	.436	.821	1.45	2.35	3.92	6.09	9.09	14.5	29.4	54.7	89.3			
300	Per V.	2355	2826	3300	3771	4242	4712	5184	5654	6600	7539				
	Air V.	2050	2458	2875	3280	3685	4100	4510	4920	5745	6555				
	Pres.	.160	.225	.302	.401	.520	.630	.760	.910	1.26	1.62				
	Cu. Ft.	2046	3363	5610	7957	11520	16250	19200	28800	44750	63629				
	H. P.	.500	.975	1.73	2.86	4.63	7.44	11.4	18.1	37.5	69.3				
350	Per V.	2747	3297	3850	4399	4949	5447	6048	6597	7700					
	Air V.	2390	2863	3345	3827	4295	4770	5262	5724	6680					
	Pres.	.216	.306	.418	.550	.693	.850	.970	1.25	1.68					
	Cu Ft.	2387	3923	6545	9282	13410	19110	22395	33400	52206					
	H. P	.663	1.28	2.38	3.89	6.65	10.7	17.2	28.3	55.8					
400	Per V.	3140	3768	4400	5028	5656	6282	6912	7540						
	Air V.	2732	3278	3830	4374	4926	5470	6013	6560						
	Pres.	.277	.399	.546	.713	.904	1.14	1.42	1.63						
	Cu. Ft.	2729	4384	7480	10620	15400	21950	25574	38300						
	H. P.	.750	1.70	3.19	5.04	9.24	15.3	25.2	39.2						

NOTE

These figures guaranteed to be correct with the resistance ordinarily found in heating work.

The theoretical relations connecting the pressure of the air, the quantity of air delivered, power to drive the fan and the speed can be stated briefly as follows: The quantity of air delivered is proportional to the peripheral velocity of the fan tips and to the width of the

fan tips. The pressure produced is proportional to the square of the peripheral velocity of the fan tips and the power necessary is proportional to the cube of the peripheral velocity of the fan tips and to the quantity

TABLE XLVI.—FAN EFFICIENCY UNDER VARYING PRESSURES.

Speeds, Capacities and Horse Powers of "A B C" Steel Plate Fans of Varying Pressures.

PRESSURES.		¼ oz.	½ oz.	¾ oz.	1 oz.	1¼ oz.	1½ oz.	1¾ oz.	2 oz.	2½ oz.	3 oz.
50	CU. FT.	2740	3900	4760	5490	6090	6700	7350	7750	8650	9520
	R. P. M.	380	540	659	760	847	930	1004	1075	1200	1320
	H. P.	.80	1.60	2.66	3 85	5 32	6.65	8.22	10.25	14.38	18.85
60	CU. FT.	3550	5040	5490	7100	7910	8700	9410	10200	11210	12330
	R. P. M.	317	449	549	633	706	776	838	895	1000	1100
	H. P.	1.03	2.05	3.42	4.95	6.84	8.54	10.60	13.2	18.45	24.3
70	CU. FT.	5220	7350	9050	10400	11600	12700	13750	14750	16500	18000
	R. P. M.	271	383	471	542	605	663	716	768	857	938
	H. P.	1.51	3.02	5.04	7.30	10.10	12.60	15.60	19.40	27.20	35.7
80	CU. FT.	630	8900	10940	12550	14000	15350	16600	17300	19890	21920
	R. P. M.	238	336	412	474	530	580	627	672	750	825
	H. P.	1.82	3.65	6.08	8.82	12.15	15.20	18.85	23.40	32.80	43.2
90	CU. FT.	7850	11050	13600	15600	17450	19100	20650	22100	24750	27300
	R. P. M.	211	299	366	421	470	515	557	596	666	734
	H. P.	2.27	4.53	7.56	11.00	15.10	18.90	23.40	29.10	40.70	53.5
100	CU. FT.	9540	13500	16500	19050	21300	23300	25200	27000	30500	33000
	R. P. M.	190	268	329	380	424	464	502	537	600	659
	H. P.	2.76	5.52	9.20	13.35	18.42	23.00	28.60	35.10	49.60	65.2
110	CU. FT.	11870	16700	20600	23600	26400	28900	31300	33500	37500	41200
	R. P. M.	173	244	300	345	385	422	456	488	546	600
	H. P.	3.43	6.85	11.44	16.60	22.90	28.60	35.50	44.00	61.7	81.2
120	CU. FT.	15000	21000	25840	29700	33200	36400	39400	42200	47100	51800
	R. P. M.	159	224	274	316	354	387	418	448	500	550
	H. P.	4.32	8.65	14.40	20.90	28.80	36.00	44.60	55.45	77.7	102.1
140	CU. FT.	19800	27900	34200	39400	44000	48200	51200	55800	63900	68400
	R. P. M.	136	192	235	271	302	331	357	383	439	470
	H. P.	5.72	11.42	19.00	27.60	38.10	47.60	59.00	73.30	102.7	135.5
160	CU. FT.	25050	35600	43700	50250	56150	61500	66500	71250	79200	87500
	R. P. M.	118	168	206	237	265	290	314	336	373	412
	H. P.	7.29	14.60	24.32	35.20	48.60	160.75	75.30	93.50	134.0	172.0
180	CU. FT.	31410	44200	54300	62700	69700	76700	82700	88400	94000	108400
	R. P. M.	106	149	183	211	235	259	279	298	334	366
	H. P.	9.07	18.13	30.24	43.80	60.48	75.5	93.6	116.20	131.0	214.0
200	CU. FT.	38000	53700	66000	75700	84950	93000	100500	107200	120000	134000
	R. P. M.	95	134	165	189	212	232	251	268	300	330
	H. P.	11.02	22.20	36.80	53.3	73.5	92.0	114.0	141.5	198.5	261.0
220	CU. FT.	46800	66300	80900	93200	104000	113500	123300	131400	147100	161500
	R. P. M.	87	123	150	173	193	211	229	244	274	300
	H. P.	13.48	27.00	44.90	65.10	89.6	112.0	139.0	173.0	243.0	318.0
240	CU. FT.	56400	79000	96500	112000	124800	136800	147400	158000	176100	194000
	R. P. M.	80	112	137	159	177	194	209	224	250	275
	H. P.	16.10	32.30	53.80	78.00	107.4	134.0	166.0	206.0	290.0	382.0

of air delivered. Mr. M. C. Huyett gives the following approximate rule for finding the capacity of a fan: The quantity of air in cubic feet delivered per revolution is equal to one-third the diameter of the fan wheel multiplied by the width of the blades at cir-

cumference, multiplied by the circumference of the fan wheel. All dimensions expressed in feet.

Professor R. C. Carpenter gives the following rule for determining the horsepower required by the fan: The horsepower required for the fan is equal to the fifth power of the diameter of the fan wheel in feet multiplied by the number of revolutions per second, divided by 1,000,000 and multiplied by one of the following coefficients—for free delivery, 30; for delivery against 1-ounce pressure, 20; for delivery against 2 ounces pressure, 10. The best method of obtaining the horsepower to drive a fan and the capacity of the fan is by reference to the table.

Table XLV gives the speed, capacity and horsepower required for various sized fans as determined by the American Blower Co.

Table XLVI gives similar results for different sized fans at varying pressure.

Table XLVII gives the results for a fan of the multi vane type, such as the Sirocco.

The table should be made use of in the following manner: Having determined the quantity of air required for the entire building, we select from the table a fan which would give the proper capacity. In doing this three things must be considered. The fan must have sufficient capacity to deliver the amount of air required. It must deliver this air with the minimum horsepower, and it must rotate with sufficient speed to product a pressure in the fan system sufficient to overcome the resistance of the piping. It is always possible to select either a small fan driven at a high speed or a large fan driven at a low speed, both of which will deliver the same capacity of air. A large fan may be

TABLE XLVII.

Speeds, Capacities and Horse Powers of Single Inlet, Standard Width Fans at Various Pressures.

Figures Given Represent Dynamic Pressures in Ounces per Square Inch. For Static Pressure Deduct 28.8%. For Velocity Pressure Deduct 71.2%.

No. of Fan	Diameter of Wheel		¼ Oz.	½ Oz.	¾ Oz.	1 Oz.	1¼ Oz.	1½ Oz.	1¾ Oz.	2 Oz.	2½ Oz.	3 Oz.
00	3	CU. FT.	38	55	67	77	87	95	102	110	122	135
		R. P. M.	2290	3230	3960	4580	5120	5600	6050	6460	7232	7920
		B. H. P.	.005	.013	.024	.037	.051	.068	.085	.105	.145	190
0	4½	CU. FT.	87	125	152	175	197	215	232	250	277	305
		R. P. M.	1524	2152	2640	3048	3400	3732	4040	4304	4816	5280
		B. H. P.	.011	.030	.053	.084	.116	.153	.193	.238	.330	.433
1	6	CU. FT.	155	220	270	310	350	380	410	440	490	540
		R. P. M.	1145	1615	1980	2290	2560	2800	3025	3230	3616	3960
		B. H. P.	.0185	.052	.095	.147	.205	.270	.34	.42	.58	.76
1¼	7½	CU. FT.	242	344	422	485	548	594	640	688	768	844
		R. P. M.	915	1290	1585	1830	2050	2240	2420	2580	2890	3170
		B. H. P.	.029	.082	.149	.230	.320	.422	.532	.656	.910	1.19
1½	9	CU. FT.	350	500	610	700	790	860	930	1000	1110	1220
		R. P. M.	762	1076	1320	1524	1700	1866	2020	2152	2408	2640
		B. H. P.	.042	.118	.216	.333	.463	.610	.77	.95	1.32	1.73
2	12	CU. FT.	625	880	1080	1250	1400	1530	1650	1770	1970	2170
		R. P. M.	572	808	990	1145	1280	1400	1512	1615	1808	1980
		B. H. P.	.074	.208	.381	.588	.82	1.08	1.36	1.66	2.32	3.05
2½	15	CU. FT.	975	1380	1690	1950	2180	2400	2590	2760	3090	3390
		R. P. M.	456	645	790	912	1020	1120	1210	1290	1444	1580
		B. H. P.	.115	.326	.600	.923	1.29	1.69	2.14	2.61	3.65	4.8
3	18	CU. FT.	1410	1990	2440	2820	3160	3450	3720	3980	4450	4880
		R. P. M.	381	538	660	762	850	933	1010	1076	1204	1320
		B. H. P.	.167	.470	.862	1.33	1.85	2.43	3.07	3.75	5.25	6.9
3½	21	CU. FT.	1925	2710	3310	3850	4290	4700	5070	5420	6060	6620
		R. P. M.	326	462	565	652	730	800	864	924	1032	1130
		B. H. P.	.227	.640	1.17	1.81	2.53	3.33	4 18	5.11	7.15	9.4
4	24	CU. FT.	2500	3540	4340	5000	5600	6120	6620	7080	7900	8680
		R. P. M.	286	404	495	572	640	700	756	807	904	990
		B. H. P.	.296	.832	1.53	2.35	3.28	4.32	5.44	6.64	9.3	12.2
4½	27	CU. FT.	3175	4490	5500	6350	7100	7780	8400	8980	10050	11000
		R. P. M.	254	359	440	508	568	622	672	718	804	880
		B. H. P.	.373	1.05	1.94	2.98	4.16	5.48	6.90	8.44	11.8	15.5
5	30	CU. FT.	3910	5520	6770	7820	8750	9600	10350	11050	12350	13550
		R. P. M.	228	322	395	456	510	560	604	645	722	790
		B. H. P.	.460	1 30	2.40	3.68	5.15	6.75	8.53	10 4	14.5	19.1
6	36	CU. FT.	5650	7950	9750	11300	12640	13800	14900	15900	17800	19500
		R. P. M.	190	269	330	381	425	466	504	538	602	660
		B. H. P.	665	1 87	3.44	5.30	7.40	9.72	12.25	15.0	20.9	27.5
7	42	CU. FT.	7700	10850	13300	15400	17170	18800	20300	21700	24250	26600
		R. P. M.	163	231	283	326	365	400	432	462	516	566
		B. H. P.	903	2.55	4 69	7.24	10.1	13.3	16.7	20.4	28.5	37.5
8	48	CU. FT	10000	14150	17350	20000	22400	24500	26500	28300	31600	34700
		R. P. M.	143	202	248	286	320	350	378	403	452	495
		B. H. P.	1.18	3.32	6.10	9.40	13.1	17.2	21.75	26.6	37.1	48.8
9	54	CU. FT.	12700	17950	22000	25400	28400	31100	33600	35900	40200	44000
		R. P. M.	127	179	220	254	284	311	336	359	402	440
		B. H. P.	1.49	4.20	7 75	11.9	16.6	21.9	27.6	33.7	47.1	62
10	60	CU. FT.	15650	22100	27100	31300	35000	38400	41400	44200	49400	54200
		R. P. M.	114	161	198	228	255	280	302	322	361	396
		B. H. P.	1.84	5.20	9.58	14 7	20 6	27.0	34.1	41.6	58.2	76.5
11	66	CU. FT.	18950	26800	32850	37900	42300	46400	50100	53600	60000	65700
		R. P. M.	104	147	180	208	232	254	275	294	328	360
		B. H. P.	2 23	6 30	11.6	17.8	24.9	32.7	41.2	50.4	70.4	92.6
12	72	CU. FT.	22600	31800	39000	45200	50600	55200	59600	63600	71200	78000
		R. P. M.	95	134	165	190	212	233	252	269	301	330
		B. H. P.	2.66	7 48	13 7	21.2	29.6	38.9	49 0	59.8	83.6	110
13	78	CU. FT.	26400	37350	45800	52800	59100	64700	70000	74700	83500	91600
		R. P. M.	88	124	153	176	197	215	233	248	278	305
		B. H. P.	3 10	8.77	16 1	24 8	34 7	45.6	57.5	70 2	98	129
14	84	CU. FT.	30800	43400	53200	61600	68700	75200	81200	86800	97100	106400
		R. P. M.	81	115	142	163	182	200	216	231	258	283
		B. H. P.	3 61	10 2	18 7	28 9	40 4	53.0	66 8	81.7	114	150
15	90	CU. FT.	35250	49800	61000	70500	78800	86400	93300	99600	111200	122000
		R. P. M.	76	107	132	152	170	186	201	214	241	264
		B. H. P.	4.14	11.7	21.5	33.1	46.2	60.7	76.7	93.6	131	172

driven at so slow a speed that it will not produce sufficient pressure to overcome resistance of the air flues. Choose the largest fan that, driven at sufficient speed to overcome the resistance of the air flue, will deliver a proper quantity of air for the purpose of ventilation. As an example: Suppose we wish to deliver to a building 10,000 cubic feet of air per minute. Referring to the table, we see that we may use an 80-inch fan driven at 400 revolutions, in which case there would be required 5 horsepower to drive the fan and the pressure produced would be .713 ounce or we might use a 120-inch fan driven at 125 revolutions per minute, in which case the power required to drive the fan would be 2.9 horsepowers and the pressure produced would be .153. In the first case the fan is small and being driven at high speed the pressure produced is more than necessary to overcome the resistance required except when the flues are long and have a number of turns. In the case of the 120-inch fan, while the horsepower is much lower the pressure is insufficient to overcome the ordinary resistance. For ordinary purposes the pressure should be about .25-.50. Referring again to the table, we see that the 100-inch fan driven at 200 revolutions per minute would require 3.15 horsepowers and produce a pressure of .274. This would be about the proper size of fan for most cases. The pressure required to overcome the resistance of the building depends very largely upon the capacity and design of the flues and the resistance of these flues is largely a matter of judgment and experience.

Heating Coils.—The determination of the proper quantity of heating coil to raise the air to a given tem-

Table XLVIII—Condensation and Heat Given Off by Heater Coils.

No. of pipes coil is deep.	No. sections in coil.	TEMPERATURE AIR ENTERING COIL 0°-10°							
		Velocity of Air 1000 feet per minute.		Velocity of Air 1250 feet per minute.		Velocity of Air 1500 feet per minute.		Velocity of Air 1700 feet per minute.	
		Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.
4	1	2.90	39	2.4	35	2.68	32	2.85	31
8	2	1.92	74	2.21	65	2.46	60	2.65	55
12	3	1.78	94	2.1	82	2.32	77	2.45	73
16	4	1.53	114	1.86	98	2.09	93	2.25	88
20	5	1.31	130	1.68	115	1.88	108	2.10	103
24	6	1.20	143	1.54	128	1.77	122	1.92	117
28	7	1.10	152	1.45	140	1.70	134	1.85	129
32	8	1.05		1.40	148	1.65	140	1.77	133

No. of pipes coil is deep.	No. sections in coil.	TEMPERATURE AIR ENTERING COIL 40°-50°							
		Velocity of Air 1000 feet per minute.		Velocity of Air 1250 feet per minute.		Velocity of Air 1500 feet per minute.		Velocity of Air 1700 feet per minute.	
		Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.	Condensation per square foot in pounds.	Temperature per square foot degrees.	Condensation per square foot in pounds.	Temperature air leaving coil degrees.
8	2	1.75	91	2.07	84	2.37	80	2.52	78
12	3	1.50	107	1.80	100	2.06	95	2.23	93
16	4	1.41	119	1.65	112	1.89	107	2.02	105
20	5	1.37	133	1.60	125	1.80	121	1.90	119
24	6	1.32	143	1.50	137	1.67	135	1.77	133
28	7	1.26	150	1.40	145	1.56	142	1.64	140
32	8	1.14	158	1.30	252	1.48	148	1.52	147

perature will depend primarily upon the amount of heat given off per square foot of heater coil.

Table XLVIII is obtained from the results of experiments made by the American Blower Company, of Detroit, and shows the condensation and heat given off by ordinary pipe heater coils under different conditions. Knowing the heat given off by the coil per square foot, under given conditions, the number of square feet of coil surface necessary may be obtained in the following

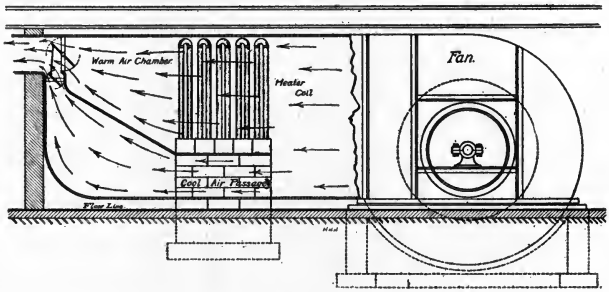


Fig. 62.

manner: Multiply the air to be passed per hour by the difference between the temperature of the outside air and the temperature of the air after passing through the coil. Multiply this product by .2375. Divide the result obtained by 13.3, multiplied by the condensation per square foot of surface per hour, multiplied by 966. Let C = condensation per square foot of coil; V = volume of air in cubic feet passing per hour; F = square feet heating surface coil should contain; t = temperature outside air; t′ = temperature of air after passing coil; then

$$F = \frac{.2375V(t'-t)}{13.3 \times 966\,C}$$

After determining the number of square feet of surface in the heater the heater must be so designed as to allow sufficient air area for the passage of air through the heater coils. The coils as ordinarily arranged are shown in Fig. 62. Sufficient area should be allowed in these coils for the velocity of air passing. This should not exceed 1,200 feet per minute, except where coils are

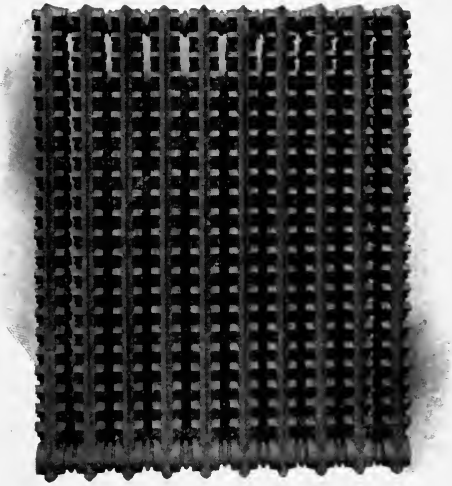


Fig. 63.

very large. Tempering coils should not be less than 12 pipes deep. If the tempering coils are made very shallow the condensation in the coil is so rapid that in cold weather they will hammer.

The heater coil consists of a cast iron base into which is screwed 1-inch steam pipes jointed at the top by nipples and elbows. The cast iron base for each section is provided with a steam inlet and drip, both connected to the cast iron heater base. Most bases are constructed

for four rows of pipes. Table XLIX gives the principal dimensions of the American Blower Company's heaters with the size of fan regularly used.

Cast Iron Heaters.—Within the last few years cast iron indirect radiators suitable for use with fans have been placed on the market. Figure 63 shows a group of ten of these sections. They are easier to handle in erection and less liable to rust. The standard sizes on the market are 41 and 60⅝ inches in length; both sizes are 9¼ inches deep and each section takes up a width of 5 inches. The 60-inch section contains 17 square feet per section and the 40-inch section 11½ square feet. The table sections are tapped 2½ inches and may

TABLE XLIX.—HEATER DIMENSIONS.

Lineal feet capacity of 1-inch pipe.	Connections. Steam.	Drip.	Bleeder.	Net air space in sq. ft.	Size of fan. Regular Disc.	Steel Plate.
200	2 "	1 "	¾"	5.4	30	80
300	2 "	1 "	¾"	7.6	36	90
400	2 "	1¼"	¾"	10.7	42	100
525	2 "	1¼"	1 "	14.3	48	110
650	2 "	1½"	1 "	17.7	54	120
825	2½"	1½"	1 "	22.2	60	140
1,175	2½"	1½"	1 "	31.	72	160
1,525	3 "	2 "	1¼"	40.	84	180
2,025	3 "	2 "	1¼"	52.5	96	200

be bushed to the proper size, depending on the number of sections composing the radiator. Fig. 64 shows a curve of the steam condensation for these radiators with varying depth of coil and different velocities of air. Figure 65 shows the temperature to which the air would be heated in passing through these coils with varying depth of coil and different velocities of air. The last two cuts are from the results given by the American Radiator Co.

Ventilating Ducts.—The success of the fan system depends very largely upon the design of the flues. The

Condensation Chart

Incoming air, 0° Fahrenheit. Steam pressure, 5 pounds

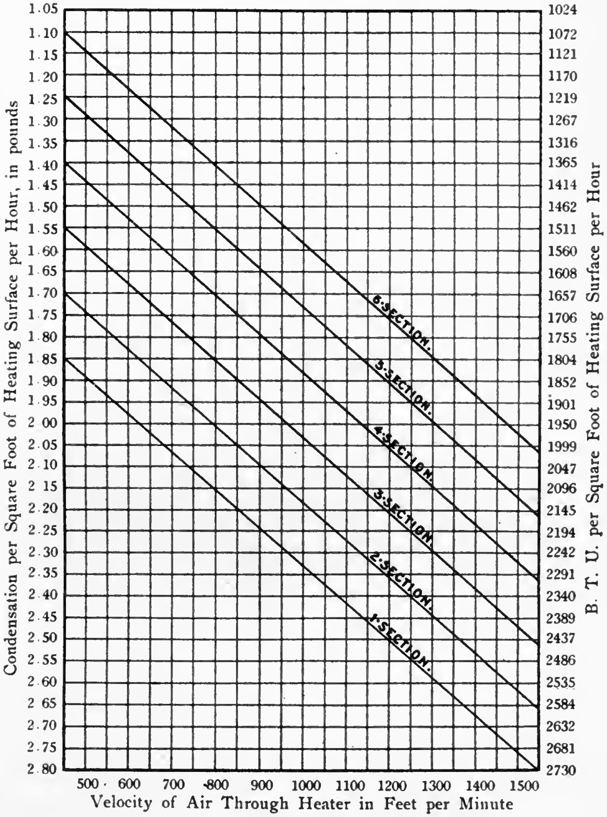


Fig. 64.

best form of flue is round, the next best form is square, or, if rectangular, is nearly square as possible. All

turns and branches should be made with easy curves. The size of the flues is ordinarily determined by the velocity of the air passing in the flues. In main ducts of large size a velocity as high as 1,500 feet per minute may be used. In the branch main or small main ducts

Temperature Chart

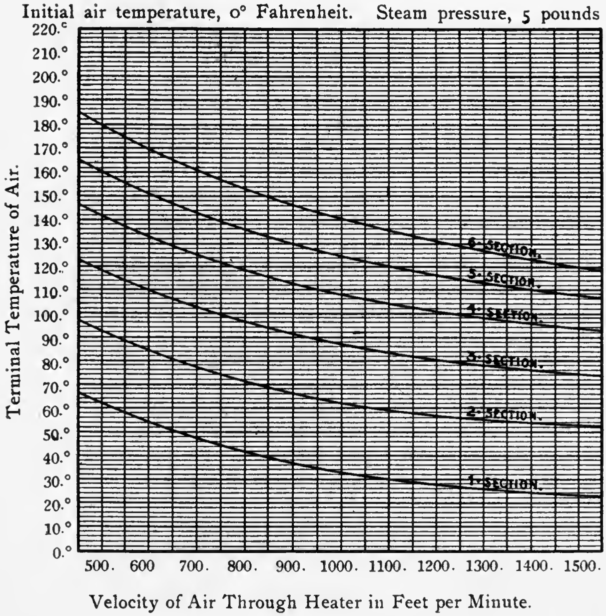


Fig. 65.

the velocity should not exceed 800 to 1,000 feet. In flues leading to the individual rooms the velocity should be from 600 to 800 feet per minute, depending upon their size. Where the ducts are of small size this velocity is often reduced to 400 feet per minute. The

velocity at the registers should not exceed 300 feet per minute except in very large registers so located that the current of air entering the room will not strike the occupants of the room, then the velocity may be 500 feet per minute. In all ordinary buildings, if these proportions of air velocities are used the resistance of the system will be from .3 to .6 of an ounce pressure. The loss of pressure in a piping system of square or round pipe may be determined from the following expression used by the U. S. Navy Department:

$$H_f = 4f \frac{l}{d} V_1^2$$

Where H is the loss of pressure due to friction measured in head of air in feet, f is the coefficient of friction, l and d are length and diameter of pipe, both in feet or both in inches, and V_1 is the velocity of flow through the pipe in feet per second. If V_1 is changed to V, or velocity in feet per minute, and f given its proper value, which for good piping is .00008, then

$$H_f = \frac{l}{d} \frac{V^2}{11,250,000}$$

$$\text{If } V = 2,000,\ H_f = .3556 \frac{l}{d}$$

$$\text{If } V = 1,000,\ H_f = .0889 \frac{l}{d}$$

For rectangular pipe of short side h and long side nh the formula becomes:

$$H_f = \frac{1+n}{n} \frac{l}{h} \frac{V^2}{2,250,000}$$

Where l = length of pipe and V is velocity of air through it in feet per minute. If a standard pressure be assumed of 5 pounds per square foot, which corresponds to a head of air of 84.25 ft., then for each foot of head lost there will be a loss in delivery of .6 or 1 per cent. For example, suppose 364 feet per minute are required at a given outlet, where the total head is 69.67, a loss of 15 feet. The corresponding loss of delivery would be 9 per cent and the rated capacity of the pipe to delivery of this air should be 364/91 = 400 cubic feet per minute.

In determining the length of a pipe a 90° elbow is equal to 5 diameters of pipe provided the radius to the center of the pipe is not less than 1½ diameters. A smaller radius than this should not be used, as it increases the resistance very rapidly. Where branches leave the main ducts it is a common practice to place a deflecting damper at the bend of the branch. This is merely a piece of galvanized iron attached to the point of the branch, which may be adjusted and fastened so that each branch will take its proper supply of air. Dampers controlled by the attendants in the building should be as few as possible. The reductions in the size of a flue should be made gradually. The angle of the reduction should not exceed a taper of 1½″ per foot. No round pipes less than 6 inches in diameter are used, and if rectangular, less than 6x8. A common arrangement of ducts is to let them radiate from the fan in the form of a tree, with trunk and branches. Another very satisfactory method of distribution is to force all the air from the fan into a large duct or chamber in which the air has a very low velocity.

The rooms take their air from this chamber by means of vertical flues controlled by proper dampers. These large chambers are called Plenum chambers. A good

TABLE L.—PRESSURE LOSSES.

Air.—Loss of Pressure in Ounces per Square Inch per 100 Feet of of Pipe of Varying Velocities and Varying Diameters of Pipes.

Velocity of Air Feet per Minute.	DIAMETER OF PIPE IN INCHES.							
	1	2	3	4	5	6	7	8
	LOSS OF PRESSURE IN OUNCES.							
600	.400	.200	133	.100	.080	.067	.057	.050
1,200	1.600	.800	.533	.400	.320	.267	.229	.200
1,800	3.600	1.800	1.200	.900	.720	.600	.514	.450
2,400	6.400	3.200	2.133	1.600	1.280	1.067	.914	.800
3,000	10.000	5.000	3.333	2.500	2.000	1.667	1.429	1.250
3,600	14.400	7.200	4.800	3.600	2.880	2.400	2.057	1.800
4,200	....	9.800	6.553	4.900	3.920	3.267	2.800	2.450
4,800	....	12.800	8.533	6.400	5.120	4.267	3.657	3 200
6,000	....	20.000	13.333	10.000	8.000	6.667	5.714	5.000

Velocity of Air Feet per Minute.	DIAMETER OF PIPE IN INCHES							
	9	10	11	12	14	16	18	20
	LOSS OF PRESSURE IN OUNCES.							
600	.044	.040	.036	.033	.029	.026	.022	.020
1,200	178	.160	.145	.133	.114	.100	.089	.080
1,800	.400	.360	.327	.300	.257	.225	200	.180
2,400	.711	.640	.582	.533	.457	.400	356	.320
3,000	1.111	1.000	.909	.833	....	....	....	....
3,600	1.600	1.440	1.309	1.200	1.029	.900	.800	.720
4,200	2.178	1.960	1.782	1.633	1.400	1.225	1.089	.980
4,800	2.844	2.560	2.327	2.133	1.829	1.600	1.422	1.280
6,000	4.444	4.000	3.636	3.333	2.857	2.500	2.222	2.000

Velocity of Air Feet per Minute.	DIAMETER OF PIPE IN INCHES.							
	22	24	28	32	36	40	44	48
	LOSS OF PRESSURE IN OUNCES.							
600	.018	.017	.014	.012	.011	.010	.009	.008
1,200	.073	.067	.057	.050	.044	.040	.036	.033
1,800	.164	.156	.129	.112	.100	.090	.082	.075
2,400	.291	.267	.239	.200	.178	.160	.145	.133
3,600	.655	.600	.514	.450	.400	.360	.327	.300
4,200	.891	.817	.700	.612	.544	.490	.445	.408
4,800	1.164	1.067	.914	.800	.711	.640	.582	.533
6,000	1.818	1.667	1.429	1.250	1.111	1.000	.909	.833

example of this is shown in the construction of the new Engineering building, University of Michigan. In this building the corridor on the ground floor has a false

ceiling about 3 feet below the second story floor. This leaves a space 3 feet high by 12 feet wide extending through the entire building. Into this space two separate fans deliver their air. The space acts as a Plenum chamber and the individual flues leaving the rooms take their air from this Plenum chamber through volume dampers which may be set and fastened after the proper position has once been determined.

Table L shows the loss of pressure per 100 feet of pipe for varying velocities and varying diameters of pipes. This table is quite liberal and allows for two ordinary 90° bends per 100 feet.

Air Mixing Systems.—Where the building is heated entirely by a fan system it is necessary to devise some arrangement by which the room may be furnished with

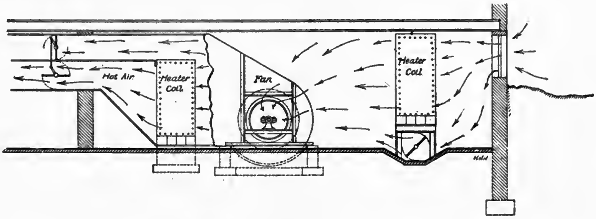


Fig. 66.

hot air or tempered air. In case the room becomes too warm, to close off the hot air register would do away entirely with ventilation and it is necessary to provide some means of introducing tempered air. The method usually is shown in Fig. 62. Where each room is connected both to the warm air chamber and to the cold air passage, the dampers being connected so that when the warm air is turned off cold air is introduced into the room, or vice versa. In this case the mixing damper is

located near the fan and preferably controlled automatically. Another system shown in Fig. 66 has entirely separate cold and hot air flues which are led to the base

TABLE LI.—DISC FAN EFFICIENCY.

Dics Ventilating Fan—Capacity, Speeds and Horse Powers (American Blower Co.)

Air Velocity in Ft. per Min.		Size Fan	18	21	24	30	36	42	48	54	60	72	84	96	108	120
600	Free	Cu. Ft.	1060	1440	1880	2940	4230	5772	7536	9540	11770	16960	23090	30156	38160	47160
		R. P. M.	327	280	245	196	165	140	122	110	98	82	70	62	55	50
		H. P.	.016	.022	.028	048	064	087	113	143	.177	253	.345	.450	573	706
	Heater	R. P. M.	530	453	396	317	267	227	197	178	158	132	113	100	89	81
		H. P.	.053	072	.094	.147	.212	.288	.377	.477	.590	.849	1.15	1.51	1.91	2.35
700	Free	Cu. Ft.	1235	1680	2200	3400	4940	6730	8800	11120	13750	19760	26950	35016	44500	55000
		R. P. M.	370	328	280	230	190	164	145	127	112	96	82	72	62	58
		H. P.	.025	.035	.045	.070	.110	.136	.178	.227	.279	.402	.548	.740	.905	1.11
	Heater	R. P. M.	600	530	458	372	307	266	234	206	178	158	132	116	100	92
		H. P.	.071	.096	.126	.196	.283	.384	.503	.636	.786	1.13	1.54	2.10	2.52	3.14
800	Free	Cu. Ft.	1410	1920	2510	3820	5650	7700	10300	12710	15710	22600	30400	40150	50900	62800
		R. P. M.	435	373	326	262	218	187	164	145	131	110	94	83	73	66
		H. P.	.036	048	.068	098	.142	.192	.251	.317	.392	.562	.766	[illegible]	1 27	1.57
	Heater	R. P. M.	705	604	527	424	353	302	265	234	212	178	152	134	118	107
		H. P.	.106	149	.189	194	.426	.579	.756	.957	1.18	1 71	2.32	3 20	3.83	4.23
900	Free	Cu. Ft.	1584	2160	2826	4410	6354	8650	11304	14310	17667	25443	34642	45234	57250	70650
		R. P. M.	490	425	368	285	246	210	184	164	146	123	106	93	82	74
		H. P.	.048	.065	.085	132	.190	.258	.338	.428	.530	.762	1 04	1.35	1.72	2.12
	Heater	R. P. M.	792	770	595	461	398	340	298	265	236	199	173	150	132	119
		H. P.	.143	.195	.254	397	.572	.780	1.02	1.29	1.59	2.29	3.12	4 07	5.15	6.36
1000	Free	Cu. Ft.	1770	2400	3140	4900	7060	9610	12560	15900	19630	28270	38480	50265	63600	78540
		R. P. M.	545	470	406	328	275	234	205	181	166	136	120	103	91	82
		H. P.	057	.080	.104	142	.233	.317	.413	.520	.647	.933	1.27	1.66	2.09	2.56
	Heater	R. P. M.	883	760	657	530	445	378	332	293	268	220	194	167	147	132
		H. P.	.204	.276	362	.565	.814	1 11	1.45	1.83	2.26	3 26	4 44	5.77	7.33	9.05
1200	Free	Cu. Ft.	2112	2880	3768	5880	8472	11541	15072	19100	23566	33900	46176	60312	76300	94240
		R. P. M.	654	560	490	398	330	280	245	218	196	164	140	124	110	99
		H. P.	.101	.138	.180	.280	.405	.550	.716	.910	1.13	1.62	2.20	2.87	3.63	4.48
	Heater	R. P. M.	1059	912	788	636	534	453	396	351	322	264	234	200	176	160
		H. P.	.300	.409	.534	.832	1.20	1.64	2.14	2.70	3.37	4.85	6.60	8.63	10.8	13.3
1400	Free	Cu. Ft.	2475	3360	4400	6850	9870	13470	17600	22270	27500	39600	53900	70300	88950	109500
		R. P. M.	767	655	570	460	388	327	286	254	230	190	164	144	128	115
		H. P.	.133	.180	.235	.368	.530	.721	.942	1.19	1.55	2.12	2.89	3.77	4.77	5.89
	Heater	R. P. M.	1235	1064	919	742	623	528	463	410	376	308	274	234	205	184
		H. P.	.487	.660	.864	1.35	1.95	2.64	3.46	4.38	5.40	7.88	10.6	13.8	19.5	21.6
1600	Free	Cu. Ft.	2830	3850	5000	7810	11300	15400	20050	25400	31400	45200	61500	80000	101200	125200
		R. P. M.	875	750	656	526	438	375	332	298	264	220	188	165	146	131
		H. P.	.185	.252	.330	.515	.742	1.01	1.34	1.67	2.06	2.97	4 05	5.28	6.68	8.25
	Heater	R. P. M.	1412	1216	1050	848	712	603	537	468	429	352	314	268	234	210
		H. P.	.735	1.00	1.31	2.04	2.94	4.00	5.23	6.62	8.17	11.8	16.0	20.9	26.5	32.7
1800	Free	Cu. Ft.	3170	4320	5630	8850	12700	17300	22600	28600	35200	51000	69000	90200	114000	141000
		R. P. M.	980	840	732	690	490	420	368	330	294	245	210	185	163	.148
		H. P.	.247	336	.440	.686	.991	1.35	1.76	2.22	2.75	3.97	5.39	7.04	8.90	11.0
	Heater	R. P. M.	1588	1368	1181	.954	801	679	595	526	483	396	354	.302	263	236
		H. P.	1.05	1.43	1.87	2.93	4.23	5.75	7.50	9.50	11.7	16.9	23.0	30.0	38.0	47.0
2000	Free	Cu. Ft.	3520	4800	6280	9800	14120	19240	25120	31800	39260	56510	76960	100520	127200	157100
		R. P. M.	1090	935	815	655	545	470	410	363	327	272	234	206	182	164
		H. P.	.336	.456	.597	.931	1.34	1.83	2.39	3.02	3.73	5.38	7.31	9.55	12.1	14.9
	Heater	R. P. M.	1764	1520	1312	1060	890	755	664	585	528	440	380	336	292	262
		H. P.	1.30	1.77	2.30	3.60	5.15	7.05	9.25	11.7	14.5	20.8	28.3	37.0	46.8	57.8
2200	Free	Cu. Ft.	3890	4300	6800	10800	15520	21130	27600	35000	43200	62200	84700	110500	139800	172500
		R. P. M.	1200	1050	900	720	600	515	450	400	360	300	257	228	202	175
		H. P.	.424	.576	.754	1.18	1.70	2.31	3.02	3.82	4.72	6.79	9.25	10.1	15.3	18.8
	Heater	R. P. M.	1940	1700	1460	1163	971	830	727	645	582	485	415	368	323	284
		H. P.	1.70	2.30	3.00	4.70	6.80	9 25	12.1	15.3	18.8	27.0	37.0	48.2	61.0	82.0

of vertical flues leading to the rooms, at which point there is introduced a mixing damper similar to the mixing damper shown in Fig. 62.

Materials of Flues.—The flues for fan systems are ordinarily constructed of galvanized iron with double lap joints riveted or soldered. The ducts should be made as nearly as possible air-tight. The weight of material used for ducts depends upon the size of the duct. It ordinarily varies from No. 26 to No. 20 gauge. Large ducts are also made of sheet iron with close riveting. When ducts are made of sheet iron the ducts are painted and then asphalted. Where it is necessary to build ducts underground they are built of brick or cement. The cement, if anything, is preferable to brick, as it does not absorb odors as easily and may be plastered to make a smooth job. Where possible it is desirable to build the ducts and flues into the building itself, making them of permanent material. Brick or cement ducts built into the building and so arranged that they may be examined and cleaned easily are the most satisfactory. Wood is always a bad material to use for ducts and should be avoided. Where it is used the ducts are lined with tin, owing to the fact that wood usually shrinks, leaving open joints.

Vent ducts from closets should be carried out of the buildings separately from the other vent flues. Where these ducts are made of brick they should be lined with galvanized iron to prevent the odors from the closet being absorbed by the brick. It is very desirable that closet vents should be collected at convenient points and then exhausted from the building by means of a fan. This prevents the odors from the toilet rooms being carried back into the building.

Disc Fans.—Disc fans are used where the resistance to be overcome is very slight or in cases where the ducts

are very large, with easy turns and of very short length. They are extensively used for exhausting the air from the vent flues and where the vent flues are short and large they give good satisfaction. The capacity, speed and horsepower of various sizes of disc fans is shown in Table LI.

EXAMPLE.—As an example of the fan system consider an auditorium. The dimensions of the room are 40 feet 9 inches by 79 feet 6 inches by 127 feet 9 inches. The volume of the room is 413,000 cubic feet. It has 203 square feet of glass surface and 5,441 square feet of wall surface. The heat lost from the room, figuring in the same way as we have for previous examples, will be 168,010 B. T. U.'s. The hall has a seating capacity of 2,500 persons. Allowing 2,000 cubic feet of air per person, the necessary air to be admitted to the room will be 5,000,000 cubic feet of air per hour. This equals 383,000 pounds. In order to heat the room with this quantity of air entering, it will be necessary to heat the air but 1.85 degrees so that the air admitted to the room for ventilating purposes will be far more than that necessary for heating purposes. It is best, then, to figure on admitting air only for purposes of ventilation. To heat this air from zero to 70° would require $383{,}000 \times .2375 \times 70 = 6{,}353{,}000$ B. T. U.'s. Referring to Table XLV, we see that a heater coil 12 pipes deep will heat air having a velocity of 1,250 feet per minute to a temperature of 82°, which is probably about the proper assumption to make in this case. The coil will condense 2.1 pounds of steam per square foot per hour. Each pound gives up about 970 heat units, so that each square foot of heater coil will give off about 2,000 B. T. U.'s per hour. Then the number of square feet of heater coil required would be $6{,}350{,}000 \div 2{,}000 = 3{,}175$ square feet.

The heater coils are usually made of 1-inch pipe and each square foot of surface is equivalent to about 3 feet of 1-inch heater pipe, hence there will be required 3,175 $\times$3 or 9,525 feet of 1-inch pipe in the heater coils. The air to be admitted to the hall is 5,000,000 cubic feet per hour or 83,300 cubic feet per minute. The usual velocity allowed for the air passing through the heater coil is 1,200 feet per minute. This will require an air area in the heater coil of 83,000$\div$1,200=69.5 square feet. The area in the various heater coils will be found in the blower company's catalogues and is also given in Table XLVIII. This will determine the size of the heater coil to be used.

On account of the size of the hall and the amount of air introduced, it will be best to have two fans for delivering air into the building. Each fan would then need a capacity of 41,650 cubic feet per minute. In order to overcome the resistance of the flues the pressure should be from .4 to .5 of an ounce at least. From the table of fan capacities we see that a 180-inch fan running at 150 revolutions would require 19.6 horsepowers and produce a pressure of .503 ounces and give the air required. Assuming the air to be delivered to the hall by four ducts, these ducts being large, it would be reasonable to allow a velocity of 1,000 feet per minute in the duct. Each duct would have to carry 20,800 cubic feet of air per minute; 20,800$\div$1,000=20.8 square feet in area. As the registers of these ducts will be large and situated well above the head line, it would be safe to allow a velocity of 400 feet per minute through the register. The area of each register, assuming that there are four entering the room, would be 26 square feet. The vent flues leaving the room should have an area about equal to the hot air flues.

CHAPTER XII.

A CENTRAL HEATING SYSTEM.

Design and Location.—It is not intended in this chapter to discuss the design of heating systems, such as is used in the heating of a city, but systems that are in use for the heating of public institutions, or groups of buildings. The type of system to be used in a given installation depends very largely upon the location and character of the building to be heated. No two systems, even though designed by the same engineer, will be the same, and the suggestions made in this chapter can be but general.

Before starting the design of a general heating system it is first necessary to have a careful survey of the property. This survey should show the exact location of the buildings to be heated, the elevation of the basement and first floor, together with a general profile of the ground through which the tunnels or pipes are to be run. The profile of the ground will largely decide the proper location of the power house. The power house should be located as nearly as possible to the buildings to be heated or as near as possible to the largest steam load. It should be low enough, if the profile of the land will permit, so that the condensation of the return mains may be returned to the power house by gravity. If possible, it should be so located that the floor of the boiler room may be drained to the sewer. Considerable difficulty is usually experienced to carry away the water, which results from the cleaning and blowing off of the boilers

if no sewer connection can be made. The question of the soil, the location of the railroad siding, the water supply and the general appearance of the power house must also be taken into consideration.

Boilers.—Before designing the power house the type and general form of boilers must be determined. If the power house is to work on a low pressure system with a pressure under 100 pounds, either fire or water tube boilers may be used. In general, for this service fire tube boilers are very satisfactory, as they have large water storage, repairs are easily made, and the boiler may be crowded considerably beyond its rating. The economy of water tube and fire tube boilers is practically the same.

The principal objection to fire tube boilers, except of the Scotch marine type, is the large space which it occupies. If the power house is to be operated on high pressure, that is, over 100 or 125 pounds, then only water tube or Scotch marine boilers can be used. The size of the boiler must be determined by the amount of steam which is to be used by the radiation and other devices taking steam from the boilers. The steam used by the different forms of radiation can be determined by reference to the radiator tables previously given, and to this must be added the steam used by auxiliaries, by the kitchen, the condensation in the main and all other devices using steam. After having once determined the quantity of steam the plant is expected to use, it is customary to assume that each square foot of heating surface in a boiler will evaporate about three pounds of water. This determines the total amount of heating surface that the

boilers should contain. The boiler units should be so selected that one boiler or one set of boilers will take care of the plant during the light load period of operation, that two boilers or sets of boilers will take care of the average operating load. In addition to this there should be a boiler or set of boilers that will take care of the maximum conditions of load. There should always be a sufficient number of boilers in the plant so that at least one boiler or set of boilers can be out of service for a considerable period of time for cleaning or repairing. In a central heating plant using the gravity return system, it is necessary that all boilers have their water line at the same level.

Systems of Distribution.

The general design of a piping system and its location will depend upon the system of distribution adopted.

Gravity System.—If the gravity return system is used no main feed pump is necessary, the water returning by gravity to the boiler, as previously described. With this system any difference in pressure between that in the boiler and that at the extreme point in the piping system will result in a corresponding elevation of the water level in the return system at the extreme point—each one pound drop of pressure in the steam piping corresponds to an increase in the level of the water in the return piping of 2.30 feet. It is essential, then, that with a gravity return system the difference in pressure between the boiler and the extreme point of the piping system be comparatively small.

The difference of pressure assumed will determine

the size of the piping. In gravity systems it is usual to allow for the drop of pressure not over two pounds between the boiler and the extreme end of the system.

In some cases the gravity return system has been used over quite an extended area, the most distant building heated being as far as 2,500 feet from the boiler, and the system has given very good satisfaction.

In a central heating plant using the gravity return system unless the steam mains are six to eight feet above the return it is necessary that the steam condensed in the mains be dripped separately from the main returns in the building and this drip pumped back to the boilers, preferably by a pump and receiver, or some other mechanical means, such as a return trap. This pump and receiver should be of sufficient size to take care of the steam condensed in the mains when the steam is being turned on and the condensation is excessive. By returning the condensation of the mains separately, excessive hammering is avoided and the system can be started much more rapidly. Gravity return is used only where the boiler pressure does not exceed ten pounds.

High Pressure System.—The high pressure steam is sometimes used for general heating purposes, but the pressure is reduced through a reducing valve before entering the radiators. It has some advantages. The pipes are smaller and circulation is very rapid in this system. It is not possible to use exhaust steam with a high pressure system. When pipe coil radiation is used it would be safe to carry a pressure up to 100 pounds on the radiators, but high pressure in the radiators is not good practice. In determining the size of steam mains for

such a system a loss of pressure as high as ten pounds would not be considered excessive. In the high pressure system each building usually sends its condensation back to the return system through a trap so that the pressure on the return is only slightly above the atmosphere. This condensation returns to a surge tank, from which the feed pumps return it back to the boilers. The drip from the steam mains is dripped directly back into the return system.

Low Pressure Pump Return System.—In a very large system where it is difficult to get enough difference in elevation between steam and return mains, or where the drop in pressure exceeds two pounds, it is usual to install some form of pump return. One of the most common forms of pump return is to trap the return condensation of each building into the return main, which carries the return back to a surge tank in the boiler room. From this surge tank the water is returned to the boiler by means of a pump. The drip from the steam main is trapped directly to the return main. The most objectionable feature of this system is the constant attendance and the repairs necessary to take care of the traps.

Combination of Power and Heating System.—In most cases the heating system is combined with some form of power system. This makes a very economical combination, as the exhaust from the power plant may be used in the heating system. Where the exhaust can be entirely utilized for from six to eight months of the year it is seldom profitable to use condensing engines.

There are two general schemes used for combining a power and heating system. In the simplest form the

boilers are operated at a high pressure. The steam goes from the boilers to the engine, and after the steam leaves the engine it passes directly to the heating system. A by-pass pipe is carried from the high pressure steam main to the heating main and in this by-pass is located a reducing pressure valve. If for any reason

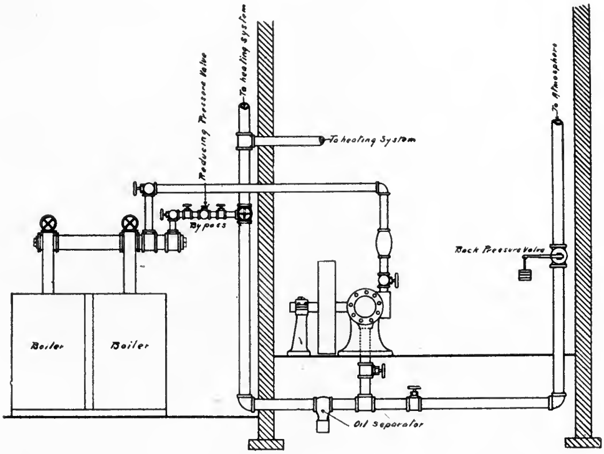


Fig. 67.

the engine does not supply sufficient steam to maintain pressure on the heating system, then the reducing valve opens and introduces live steam. The returns from the heating system are carried back to the boiler by means of a pump.

Fig. 67 shows the general arrangement of systems of this kind with a by-pass for furnishing live steam to a heating system. This system depends in a measure for its success upon the action of the reducing pressure valve.

The cross-section of a reducing pressure valve is

shown in Fig. 68. Such valves have been found to be quite reliable when well designed and well made. The principle cause for trouble is when the valve becomes foul with dirt. In a system of this kind the engine exhaust is always provided with a back pressure

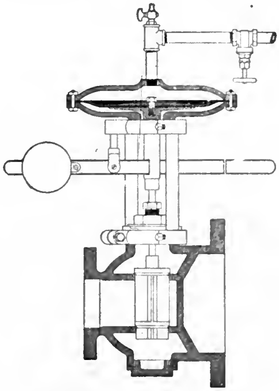


Fig. 68.

valve connected to the atmosphere. This valve is so arranged that if for any reason excessive pressure should accumulate in the heating system the valve would open and exhaust the steam into the atmosphere. The arrangement shown in Fig. 67 is most used in small plants and both the heat and the power can be taken from one boiler. In larger plants the heating boilers are operated on the low pressure and the power boilers on the high pressure system. In the high pressure system steam goes to the engine and pumps and is exhausted through an oil separator into the low pressure system. The pressure of the exhaust is determined by the pressure carried on the low pressure system. This system is particularly desirable where the heating load is con-

siderably larger than the power load; and where at times the engines are entirely shut down and only the low pressure system is operated. Fig. 69 shows a sketch of this arrangement.

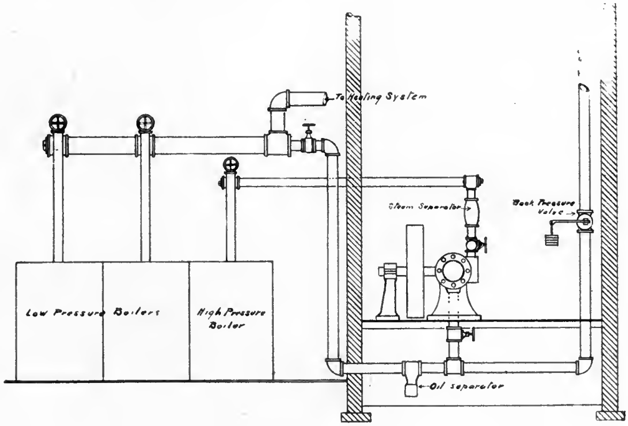


Fig. 69.

Method of Carrying Pipes.—In carrying pipes from one building to another it is always desirable, if possible, to carry them underground. Carrying underground affords much better heat insulation, the pipes are more easily supported and are less apt to be disturbed. The simplest method of underground distribution and the cheapest is to enclose the pipes in a pine board case, as shown in Fig. 70. This arrangement, however, is not as desirable as a tunnel system, the heat insulation is not as satisfactory and the pipes are more difficult to get at for repairs. Its chief recommendation is that it is cheap. In most cases it should be used for work where the expense of a tunnel system would not be warranted.

A system quite largely used is to enclose pipes in pump logs, that is, hollow wooden pipes. These pipes are creosoted and filled with an asphalt paint or some other means of preservation. They are often lined with tin or some other form of metal lining. The pipe is passed through the pump log and is usually covered with about one inch of some standard form of pipe cover-

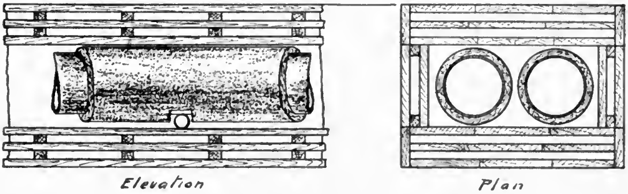


Fig. 70.

ing. This method of running the pipes furnishes quite satisfactory heat insulation. It is much more durable than the pine board duct, it is easier to install and easier to replace in case of repairs. It has, however, the disadvantage of making the pipe quite inaccessible and in case of accident the removal of the entire system is necessary; this in many places is very expensive. The builders of one of these pipe ducts stated that the loss in the pipes enclosed in this manner is from one-fourth of one per cent to six per cent per mile of pipe delivering steam at its full capacity. The larger the pipe the smaller the proportional heat loss. Fig. 71 shows a cross section of a pipe log with covering. This pipe log construction is most used in central heating systems for building connections and where only one pipe is to be used in supplying the building.

Where it is necessary to run a number of pipes the most desirable method is to run through tunnels made

of brick or cement. The size and form of tunnel used will depend upon the number of pipes to be carried, the character of the soil and the depth into the ground. Where tunnel systems have been installed the general experience has been that they more than paid for themselves in a short time, as they entirely do away with the necessity of taking up the pipe and allow for repairs

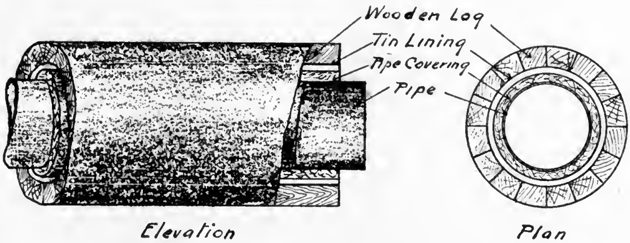


Fig. 71.

and frequent inspection. Fig. 72 shows a small sized tunnel. This tunnel has been used for carrying pipes not over 8 inches in diameter. The tunnel is 3 feet 6 inches wide, 4 feet 6 inches high. It is made of brick 4 inches thick, with 1 inch of Portland cement outside. This cement is painted a thick coat of tar or asphalt to below the crown of the arch. Wherever the supports come the tunnel is ribbed with an 8-inch rib of brick 16 inches wide. This rib is placed about every 10 feet. A tunnel of this kind has been in use for some time and has given good satisfaction. It is not desirable to use this sort of tunnel for large pipe or where the tunnels are to be frequently inspected.

For larger pipes the section shown in Fig. 73. is much more desirable. This tunnel is 5 feet by 6 feet inside dimensions. The tunnel is made of two

courses of brick or about 9 inches thick. It is plastered on the ontside with 1 inch of cement and then tarred down to the crown of the arch. At the lowest point of the tunnel on each side is shown a 3-inch tile, which serves to carry away the drainage around the tunnel. If possible, this 3-inch tile should be brought to some drain. In moist clay soils it is sometimes found

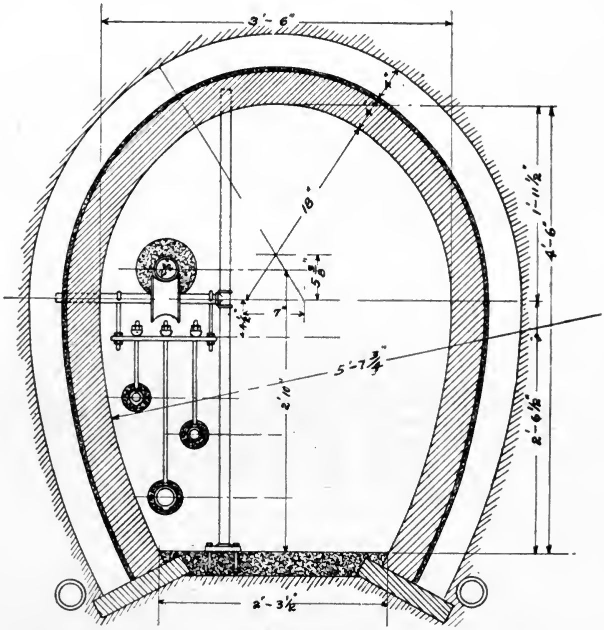


Fig. 72.

necessary to run a tile under the middle of the tunnel, connecting with the inside of the tunnel so that seepage through the tunnel walls may be carried off either to the sewer or to the pumping plant. In sand and in gravel soils this is not necessary, as almost no difficulty

would be experienced from leakage. Fig. 74 shows a tunnel made for carrying two large pipes. The tunnel is 5 feet 6 inches by 6 feet 6 inches and gives ample

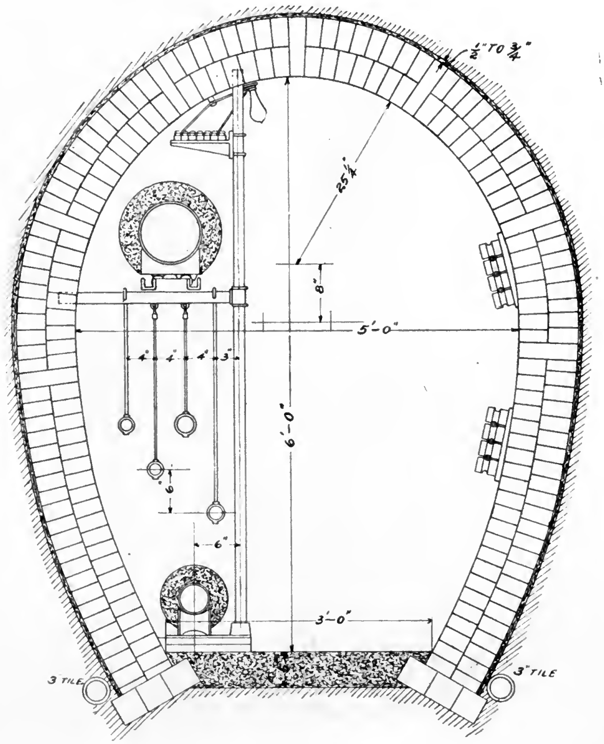


Fig. 73.

passageway between the pipe supports for easy access at all times.

The cost of tunnels depends upon the nature of the excavation and the price of materials. To give an approximate idea of what tunnels cost, the tunnel shown in

Fig. 72 has been constructed, including excavation, back filling and all necessary material, for $7.00 per linear foot. The tunnel shown in Fig. 73 has been constructed for $8.00 per linear foot, and the tunnel shown in Fig. 70 has been constructed for $9.00 per linear foot.

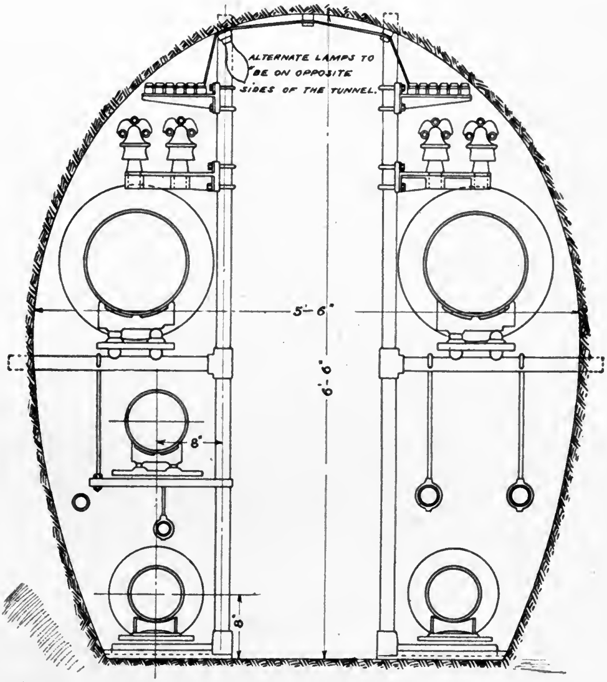


Fig. 74.

Sizes of Pipes.—The size of the pipe necessary to carry a given quantity of steam is determined by the allowable loss of pressure that the system will permit. In a low pressure system this loss of pressure should not exceed 2 pounds. In a high pressure system it should

not exceed 10 pounds. The rule most commonly used is called Babcock's rule, and is as follows:

Let W = weight of steam in pounds flowing per minute.

w = the weight of a cubic foot of steam.

p_1 = pressure in pounds per square inch of steam entering pipe.

p_2 = pressure in pounds per square inch of steam leaving the pipe.

d = diameter in inches.

L = length of pipe in feet.

$$\text{Then } W = 87 \; \frac{w\,(p_1 - p_2)\,d_5}{L\,(1 + \frac{3.6}{d})}$$

The best way of handling this expression is to assume different diameters of pipe and then try a number of standard pipe sizes. In this way determine the pipe size which approximates most closely the weight of steam which it is desired to carry.

In low pressure gravity return systems the return is usually taken as one-half the pipe size of the steam main up to 10 inches. Above 10 inches the size is taken as one-half the size of the steam main minus one size. As, for example, a 10-inch main would require 5-inch return, a 14-inch would require a 6-inch return. The size of drip main for a given steam main depends entirely upon the length of the main. It should never be less than ¾-inch and it is seldom necessary to make the pipe over 1¼-inch. A 1¼-inch drip main will take care of 2,000 feet of 12-inch pipe, providing the pipe is well covered with standard covering.

Hangers and Anchors.—When pipes are carried through tunnels it is necessary to provide a different form of hanger than in building work. In tunnel work the head room is so limited it is ordinarily impossible to suspend pipes from above and they must have some form of roller hanger. Fig. 74 shows ball-bearing hangers for 12-inch pipe and roller hangers for the 6-inch pipe. Fig. 72 shows a very simple form of roller hanger. Fig. 73 also shows a form of ball-bearing hanger for 8-inch pipe and roller bearing for 4-inch pipe. The ball-bearing hangers shown in these figures have given very satisfactory results. They are expensive, but the expense is warranted. In tunnel work the clearance is so small that it is necessary to know exactly where the expansion is to be taken up. The only way to be certain of this is to anchor the pipe at the point desired. These anchors are usually made of heavy cast iron with wrought iron straps enclosing the pipe. The hangers should be built into the tunnel or building walls and should pass entirely through the wall, projecting 4 inches or more on the opposite side of the wall. The anchors should not be built into walls that are less than 12 inches thick, and preferably they should be 16 inches thick. In putting in hangers and supports in tunnel work it is a very important thing to see that a clear space is left through the center of the tunnel which will give easy access to the tunnel. The easier the access and the more comfortable the tunnel for passage, the more frequent will be the inspections, and such inspections insure of the piping being kept in the best possible condition.

Air Valves.—Fig 75 shows an air valve adapted for use on large heating systems. The outlet of this air valve is three-quarters of an inch in diameter. It is particularly designed to take care of the air in the

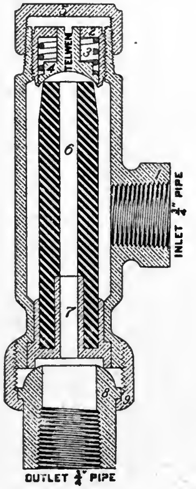


Fig. 75. Air Valve for Use on Steam Mains.

building and tunnel mains. The ordinary sized valve used in radiators is entirely insufficient to take care of large mains. Piping that is 4 inches and over should have the larger valves. With still larger piping, 10 or 12 inches in diameter, where the mains are 400 or 500 feet long, even this size is hardly sufficient to take care of the air unless a number of them are used.

The valve shown in Fig. 76 is often used. This consists of a brass pipe "A" four feet long, to which is screwed a 1¼-inch angle valve. This pipe and angle valve are attached by a suitable elbow and

nipple to the main from the point at which the air is to be removed. A yoke is fastened at elbow "B" and to this yoke two iron rods are attached. These

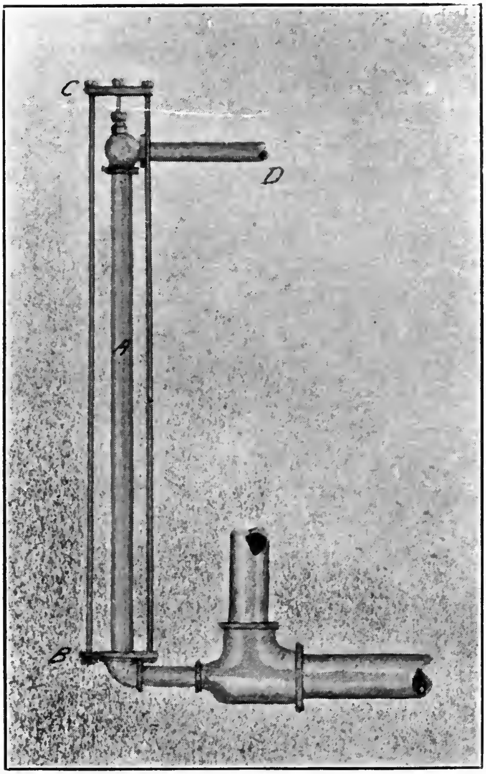


Fig. 76.—This Form of Air Valve is Often Used.

iron rods are connected at the other end of the yoke "C." Yoke "C" is attached to the valve stem of the angle valve. The threads are removed from the stem

of the valve so that the valve will pass freely through the stuffing box. By means of a lock nut on the valve stem the height of the valve disc above the seat may be adjusted. To start with, however, the brass rod "A" will be cold and the valve disc will be off the valve seat and air will be alowed to pass out pipe "D." As soon as steam comes the brass pipe "A" expands, bringing the valve seat up against the disc and closing the valve so that no steam can escape.

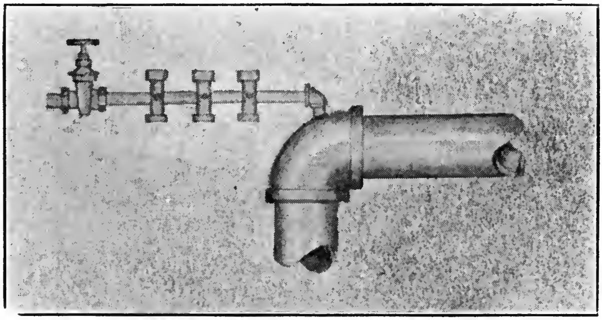


Fig. 77. Air Valve to Relieve a Fitting and Line of Pipe from Air.

Another arrangement that may be used is shown in Fig. 77. At the point at which it is desired to remove the air a 1-inch pipe is tapped into the fitting. Into this is tapped a 1-inch nipple, an elbow and a short piece of pipe, as shown. At the end of this short piece of pipe is attached a gate valve. At intervals along the inside of the pipe are attached large air valves, such as the one shown in Fig. 75. On starting up the system the gate valve is left wide open and remains open until steam begins to blow, then this gate valve is closed and the small air valves take

care of the accumulation of air that occurs from time to time.

Lack of proper air valves may cause serious accidents in the pipe system. In large pipes when steam is turned on it will circulate along the top of the pipe and the cold air remains at the bottom of the pipes; the upper side of the pipe will then be hotter than the lower and hence will expand more than the under side. The tendency of the pipe is to assume a circular form, as shown in Fig. 78 by dotted lines. In

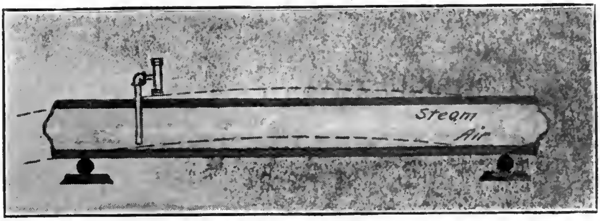


Fig. 78. How Air Collects and Sometimes Breaks a Piping System. How It Is Prevented.

case of a very large pipe this has been known to wreck the piping system, breaking flanges and springing the valve seats. Such a condition may be prevented by running the air pipes on the mains down to the bottom of the main, as shown in the figure, so that the air is removed from the bottom of the main instead of from the top of the main. In long piping systems it is very desirable that at intervals of not more than 100 feet air valves should be placed to remove the air from the bottom of the main. The size of these valves will depend upon the size of the main and they should be of ample capacity. It is not always necessary to use automatic valves. Auto-

matic valves can be replaced by ⅜-inch or ¼-inch valves for this purpose.

Air valves should be located at all high points on the return main, particularly at points where the return main rises, passes along the horizontal, and then drops down again. At such points air valves should be located at the top of the main. If this is not done the air will accumulate at these high points and prevent passage of water, sometimes almost as effectively as though the main were valved at these points.

Surge tanks, traps and other devices where air may accumulate should be provided with air valves. In fact, when trouble is experienced in a steam pipe system one of the first things that the builder should assure himself of is that the air is being properly removed from all parts of the system.

COMBINATION OF STEAM AND HOT WATER SYSTEM.

There are a number of systems using a combination of exhaust steam and hot water for use in connection with central heating systems. The exhaust from the engine is passed through an exhaust heater and the water heated in this heater is circulated through the heating system by means of a pump. In this way exhaust steam can be used for heating a large territory without producing any back pressure. This form of heating may be used in connection with a condensing engine. The water being circulated by a pump under pressure insures its actual circulation throughout the whole system and makes possible the use of relatively small mains for heating purposes,

smaller than would be required for either low pressure steam or exhaust steam. In addition to the exhaust steam heater there may be used either a hot water boiler or an auxiliary live steam heater, so that in case the exhaust is insufficient for heating the water, the water may be passed through this live steam heater, bringing it up to the proper temperature. In some cases a Greene economizer has been used for furnishing additional heat, thereby making use of the waste from the boiler.

Systems of this kind have been installed in a number of cities and as high as one thousand houses heated from a central heating system. In these hot water circulating systems two general forms of pump are used, either a centrifugal pump driven by a motor or engine, or a piston pump of the ordinary type. In most cases unless a high pressure is desired, a centrifugal pump is desirable. The central hot water heating system has one particularly desirable feature—the hot water leaving the system may be adjusted to correspond with the external temperature. The size of hot water mains is determined from the velocity of water circulating in the main. In small mains it should not exceed 2 feet per second; in large mains it may be as high as 4 feet per second.

Central heating by means of hot water is particularly adapted for residence districts, as the system can be installed with less expense per foot of main, making it possible to cover profitably an area having the houses scattered. Central heating with steam is particularly adapted for close business districts where steam is the usual form of heating and where the piping system will be relatively short for the load carried.

In connection with the systems using pressure there must be used some form of expansion tank. Some of these systems use an open expansion tank, allowing the water in the return system to enter this open tank at practically atmospheric pressure, the suction of the circulating pump being connected to this open tank. Where this system is used a piston type of pump would probably be a desirable form. Where the centrifugal type of pump is used it would be desirable to use a closed tank. In this case the tank is partly filled with water and partly filled with air. The expansion and compression of the air allows for the change in the volume of water due to changes of temperature conditions. In this case the pump will then only furnish the pressure necessary to overcome the resistance of the piping system. The air side of the expansion tank should be provided with an air pump, so that pressure may be maintained by means of an air pump on the air side of the system and the proper quantity of air carried in the tank at all times.

CHAPTER XIII.

PIPING, COVERING AND OTHER APPLIANCES.

Pipe Covering.—In all piping installation it is customary to cover the distributing pipes, except radiator connections. It is good practice to cover the risers passing through buildings, together with all steam and return mains. Where the water mains pass through rooms in which any drip from the pipes would be objectionable, such pipes are also covered to prevent the condensation of moisture on the outside of pipes. In general the best form of non-conductor is dry air, which is so confined as to prevent circulation. In all successful forms of covering air is confined in the structure of the covering and the effectiveness of the covering depends largely upon the confining of this air. The effectiveness of different forms of covering was determined in a series of experiments made under the direction of Prof. M. E. Cooley, University of Michigan. Table LII shows the relative effectiveness of some of the different forms of covering.

The results of these tests show that hair felt is the best non-conductor. It is not, however, suited for over 5 pounds pressure, as it chars and breaks down at higher pressure owing to the higher temperature; this is also true of the wool felts. In low pressure work at such temperatures as are ordinarily used, hair felt is found to be quite satisfactory. It is expensive, but its expense is warranted in the saving from condensation in the piping.

TABLE LII.

Relative Value of Different Pipe Coverings.

Material of covering	Lbs. of steam condensed per sq ft. covered pipe per hr.	Ration of condensation of covered pipe to bare pipe.	Thickness of covering, inches.	B. T. U.'s transmitted per sq. ft. per hr.	Relative insulating value compared to 1 in., hair felt.
Moulding coverings.					
1. Asbestos	.145	.319	1.23	136.	.803
2. Magnesia	.119	.224	.94	166.	.915
3. Magnesia and asbestos.	.125	.300	1.12	118.	.879
4. Asbestos and wool felt..	.190	.228	1.12	102.	.910
5. Wool felt	.117	.234	1.16	110.	.904
6. Wool felt and iron with air space	.134	.269	...	125.	.828
Sectional Coverings.					
7. Mineral wool	.097	.193	.94	91.	.952
8. Asbestos sponge	.105	.220	1.12	102.	.920
9. Asbestos felt	.100	.217	1.35	94.	.923
10. Hair felt	.080	.186	1.45	75.	.960
Non-Sectional Coverings.					
11. Two layers asbestos paper	.388	.777	...	364.	.263
12. Two layers asbestos paper, one inch hair felt and one thickness canvas	.070	.150	...	68.	1.000

Table LIII shows the relative effectiveness of different thicknesses of covering. Column 3 of this table shows the relative effectiveness of the various thicknesses of covering compared with the bare pipe. From this table it is not a difficult matter to figure the amount of saving that may be made by using various

TABLE LIII.

Heat Transmission for Varying Thicknesses of Covering.

Thickness of covering. inches.	Condensation per sq. ft. per hour in pounds.	Ratio of Condensation covered to bare pipe.	B. T. U.'S transmitted per sq. ft. per hour.
½	.120	.281	167.
¾	.117	.255	163.
1	.107	.231	149.
1½	.099	.219	138.
1¾	.087	.191	121.
2	.078	.19	108.

The covering used in obtaining the above results was a wool felt.

thicknesses of covering. Knowing the amount of steam carried per year and the cost to produce 1,000 pounds of steam, and having the results shown in this table, we can easily compute the financial saving to be made in the various thicknesses of covering. In doing this it is usually found that for building work an inch covering is sufficiently heavy; but for tunnel work and all work where the heat loss from the pipe is entirely lost and does not enter the building it is economy to use covering 2 inches thick. Where superheated steam is used at high temperatures the covering is from 3 to 5 inches thick. Table LIV shows the heat lost through a 1-inch wool covering with various steam pressures. In covering a piping system the fittings and valves should be covered the same thickness as the pipe. This also applies to flanges and steam traps. Where flanges and other parts which require removal are covered they should be covered so that the covering can be taken off easily. A satisfactory method of doing this is to form a covering composed of one layer of asbestos paper, 1 inch of hair felt and one thickness of 8-ounce duck. These are quilted together with cord so that the jacket is firmly held in one piece. This covering is then fastened over the pipe to be covered by means of hooks and laces.

TABLE LIV.

Heat Transmission for Varying Pressures.

Gauge pressure.	Condensation per sq. ft. per hour.	Ratio of Condensation of covered to bare pipe.	B. T. U.'s Transmission per sq. ft. per hour.
5.3	.108	.239	100.
9.6	.111	.233	104.
15.5	.126	.227	110.
20.5	.134	.223	119.

The advantage of covering may be shown from the following computation:

Example.—In a given steam plant it was found that the heat lost from bare pipes per hour was 3,355,000 B. t. u. In the particular plant in question the number of heat units required to make a pound of steam was 990, and this loss of heat would represent a condensation of 3,390 pounds of steam per hour. Assuming an evaporation of 9 pounds of steam per pound of coal this would be equivalent to 376 pounds of coal per hour. If the plant were operated 365 days in the year and 20 hours a day, and the coal cost $3.25 per ton, the yearly loss would be $2,069. By covering the pipe 1 inch thick with hair felt the loss which would result from the bare pipe would be reduced to 15 per cent, which equals $314, making a saving of $1,755 by putting on covering. This amount capitalized at 10 per cent would represent an investment of $17,550. In the particular case in question the actual cost of the covering was but $3,500.

Air Valves.—In steam piping work it is very important that the piping system be provided with sufficient number of properly located air valves. Primarily, air valves should be located at the points in the piping at which air accumulates in quantity. We are familiar with the fact that when a radiator is not provided with an air valve steam will not circulate into it and it does not become warm. This is also true of both steam mains and the return system. The writer has seen the entire return system of a building plugged with air on account of there being no air valve on a high point in the return main.

For radiators an air valve similar to that shown in Fig. 79 is usually used. You will notice that this

air valve allows air entering from the connection to the radiator to pass directly to the top of the air valve body and out through a small hole or opening, which may be adjusted by means of a screw plug. If water enters the air valve, the water will rise in the valve body until the copper float, having a pin on its upper end, rises so as to close the exit from the air valve,

Fig. 79. Type of Air Valves Commonly Used in Radiators.

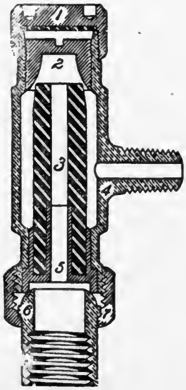


Fig. 80. Air Valve Used on Radiators in Connection with Paul Valve.

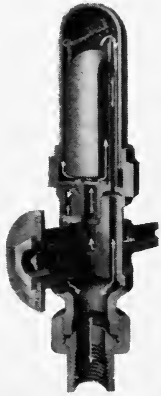


Fig. 81. Air Valve Adapted to Hot Water Work.

and no water is allowed to escape. When steam enters the air valve the expansion plug shown at the center of the air valve expands, raising the copper float, again closing the outlet from the air valve.

Fig. 80 shows an air valve which is used for radiators in connection with a system of air piping from the air valves. (1) is a cap screw screwed down on the valve with a lead washer, making a tight seat. (2) is a hollow screw upon which the expansion post (3) sets, closing the valve. The adjustment of the valve is done with screw (2), and this may be done

without disturbing the valve. (3) is a hollow part fastened at (5) and held in place by the union (6). This should never be disturbed. (4) is the nipple of the valve body, by which it is attached to the radiator. This is the union for attaching to the piping of the Paul system or other air piping system. (7) is a nut which forms the union for attaching this piping. The operation of the valve is as follows: The air is drawn in from the radiator through nipple (4) into the valve between the adjusting screw (2) and the composition part (3) passing down through (3) into the pipe. When steam enters the composition part becomes heated and expands, thereby closing the opening between (3) and (2). When air again accumulates and cools this composition part contracts, permitting air to be drawn through the tube.

There are two typical forms of air valve, one closing off the air by the action of the float, the other closing off the air by the action of heat expanding a plug. Fig. 79 shows a combination of these two principles, which prevents the throwing of water or the discharging of steam.

Fig. 80 exemplifies the simple expansion operation. The valve shown in Fig. 80 would allow cold water to pass.

Fig. 81 shows an air valve particularly adapted to hot water work. In this air valve the float principle alone is used. Air enters in through the connection to the radiator, as shown by the arrow in the cut, passes under the float and escapes through a small tube which reaches to a point near the top of the air valve. As soon as the water enters the float lifts, due to the air compressed by the water under the float,

Table LV.

WROUGHT IRON AND STEEL STEAM, GAS AND WATER PIPE

TABLE OF STANDARD DIMENSIONS

Diameter			Circumference		Transverse Areas		Length of Pipe per Sq. Ft. of		Length of Pipe Containing One Cubic Foot	Nominal Weight Per Foot	Number of Threads Per Inch of Screw
Nominal Internal	Actual External	Approximate Internal Diameter	External	Internal	Internal	Metal	External Surface	Internal Surface			
In.	In.	In.	In.	In.	Sq. In.	Sq. In.	Ft.	Ft.	Ft.	Lbs.	
⅛	.405	.27	1.272	.848	.0573	.0717	9.44	14.15	2513.	.241	27
¼	.54	.364	1.696	1.144	.1041	.1249	7.075	10.49	1383.3	.42	18
⅜	.675	.494	2.121	1.552	.1917	.1663	5.657	7.73	751.2	.559	18
½	.84	.623	2.639	1.957	.3048	.2492	4.547	6.13	472.4	.837	14
¾	1.05	.824	3.299	2.589	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	4.131	3.292	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	5.215	4.335	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	5.969	5.061	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	7.461	6.494	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	9.032	7.753	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	10.996	9.636	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4.	3.548	12.566	11.146	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	14.137	12.648	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	15 708	14 162	15.961	3.674	.764	.848	9.02	12.49	8
5	5.563	5.045	17.477	15.849	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	20.813	19.054	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	23.955	22.063	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	27.096	25.076	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	30.238	28.076	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	33.772	31.477	78.839	11.924	.355	.382	1.82	40.065	8
11	11.75	11.	36.914	34.558	95.033	13.401	.325	.347	1.51	45.028	8
12	12.75	12.	40.055	37.7	113.098	14.579	.299	.319	1.27	48.985	8

Piping is often designated as "Merchant Pipe." This term is used to indicate soft steel pipe taken from stock. In sizes from ⅛ inch to 6 inch it is about 5% under the card weight and about 10% under card weight for sizes above 6 inch. Full weight pipe is made of stock that will produce pipe of full card weight.

and the rubber valve held by the rim closes the opening through which the air escapes. The valve as shown here is made for connection to an air valve piping system. A similar valve is made without this connection. In the air valve shown for connection to a piping system there is a three-way plug cock in the air valve, which allows of air and water being drawn directly to the air pipe system and of being entirely closed off.

Pipe.—Piping for heating systems is made either of wrought iron or mild steel. An extra price must be paid for wrought iron pipe. The smaller sized pipes up to and including 1¼ inches are butt welded and are tested to 300 pounds pressure. Large sizes are lap welded and tested to 500 pounds pressure.

Pipe is shipped in lengths of from 16 to 20 feet and is threaded at both ends, but a coupling is put on only at one end.

The standard size pipes in use are given in table No. LV.

Piping is often designated as "Merchant Pipe." This term is used to indicate soft steel pipe taken from stock. In sizes from ⅛-inch to 6-inch it is about 5 per cent under the card weight and about 10 per cent under card weight for sizes above 6-inch.

Full weight pipe is made of stock that will produce pipe of full card weight.

Both steel and wrought iron piping is designated as wrought iron pipe. If wrought pipe is desired it should be called "strictly wrought iron pipe."

Piping is made in three weights—standard pipe, the dimensions of which are given in Table 42; extra

strong pipe, suitable for working pressures up to 250 pounds; double extra strong pipe, suitable for working pressures up to 500 pounds.

Fittings.—For heating work standard weight cast iron screwed fittings are used up to 6 or 8 inches in diameter. Above that it is usual to use flange fittings.

When screwed fittings are used, flanges must be placed in the piping to provide for disconnecting in case of repairs. In screwing pipes into fittings the pipe grease should always be placed on the pipe threads so that the excess will not be left in the fittings.

In describing a tee always give the dimensions of the "run" first and of the side outlet last. A bullhead tee is one in which the side outlet is larger than the outlets in the "run."

It is better practice to use reducing elbows or reducing tees than to use standard tee or elbows and reduce them by means of bushings.

Valves.—Valves 2 inches and under are made of all brass with removable discs. For radiators where the piping comes through the floor, angle valves are used. Where the piping comes over the floor offset or corner offset valves are used. Gate valves should be used in horizontal lines of piping which carry condensation. Globe valves may be used in vertical pipes but not in horizontal pipes, as they dam up the water passing in the pipe.

Where check valves are used they should be of the swinging check pattern.

Valves above 2 inches are usually used with iron bodies and brass mountings and should have renewable disc seats.

CHAPTER XIV.

AUXILIARY DEVICES FOR HEATING SYSTEM.

A temperature regulator is an automatic device which will open and close the valve of the radiator so as to keep the room at a constant temperature. The temperature regulator in general consists of three parts. *First*, a thermostat which is so constructed that its parts will move with a change of temperature in the surrounding air and the motion of these parts will directly or indirectly open the dampers or valves which control the heat supply. *Second*, there must be some means of transmitting the motion from the parts of the thermostat to the valves or dampers controlling the heat supply. *Third*, some form of mechanism for opening the valves or dampers. In most temperature regulating systems the thermostat merely furnishes power enough to close or open an air valve or electric switch and thus start or stop the operation of the valves or dampers.

The form most used at the present time uses compressed air to operate the valves and dampers. In the Johnson thermostat a small air valve is opened by the expansion of a curved strip composed of two materials having different rates of expansion. The bending of this strip due to change of temperature allows the air to escape and a small diaphragm to move back, thus opening a second valve allowing the air to come from the compressor or source of air supply and close the valve or damper on the radiator. When the room becomes cool the contrac-

tion of this strip closes the first small valve forcing out the diaphragm and closing off the compressed air supply to the valve or damper and releasing the air already in the valve or damper. Another form of thermostat extensively used is operated by means of a liquid confined in a thin metal vessel, the liquid

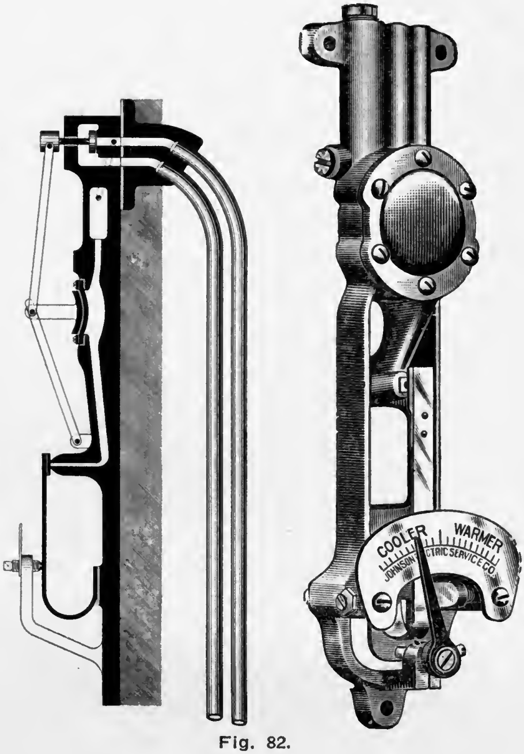


Fig. 82.

having a very high degree of expansion. As the liquid expands or contracts it controls the system of valves controlling the heat supply to the room.

Temperature regulation is a desirable thing in all large heating systems, particularly for public build-

ings. The systems are quite expensive, but the expense of construction is more than offset by the saving in fuel bills. The saving in fuel bills in most cases is not less than 15 per cent and often as high as 20 per cent. In general the operation of these systems has been entirely satisfactory even after they have been in use some time without any attendance. The control of the temperature of the room should be regulated within 3 degrees. With proper care these systems should control the temperature of the room within 2 degrees. Temperature regulating apparatus is particularly desirable in school rooms; this places the temperature of the room outside the control of the instructor and it is then free from his own personal ideas in the matter, thus adding much to the health and comfort of the occupants of the room. With the fan system it is difficult to get satisfactory operation without temperature regulation. The application of temperature regulation to the fan system is shown in Fig. 83.

Air Piping System. The discharge of air from the air valves and radiators often produces a very disagreeable odor and in addition it is very difficult to obtain an air valve which will not at times discharge a certain amount of steam or water. This difficulty may be overcome by using an air valve so designed that the discharge connection to the valve can be fastened to a piping system. The pipes and air valves are carried to the basement, collected into a larger pipe and discharged to a sewer or suitable vessel. A system of air piping is very desirable, particularly in large buildings, such as hotels and office buildings. where it saves materially in the attendance necessary

to keep the plant in operation. It is also desirable in nice residences where any discharge of water or steam might injure the furnishings. In case it is desirable to install a vacuum system of heating this system could be connected directly to a vacuum pump insuring more rapid circulation in the radiation.

Damper Regulators. It is always desirable in a steam or hot water heating plant, particularly steam, to install some form of damper regulator on the boiler. In some heating plants it consists of an ordinary rubber diaphragm enclosed in a metal case. The steam is allowed to come in contact with one side of the diaphragm, pushes a lever attached to the other side of the diaphragm. This lever operates a damper controlling the air supply to the fire and sometimes also operates the check valve in the breeching. This is a very desirable arrangement, as it reduces the attendance necessary to keep the pressure in the boiler at the point desired.

Humidity Regulation.—The humidity of the atmosphere is a very important consideration in any heating system. When the air is very dry it is necessary for a room to have a much higher temperature in order that it may feel comfortable than when the air is moist. It is, therefore, important that we keep the humidity at a point as high as consistent with satisfactory operation. Cold air contains proportionately less moisture than warm air, and therefore when cold air is heated and brought into a building it should be moistened in order to keep a proper per cent of humidity. The average humidity is about 70 per cent, in the arid regions humidity may be as low as 30 per cent. Humidity as low as 30 per

cent produces irritation of the lungs and smarting of the eyes. In cold weather, if the humidity of the outside air is 70 per cent and this air is heated and brought into the room without moistening, its humid-

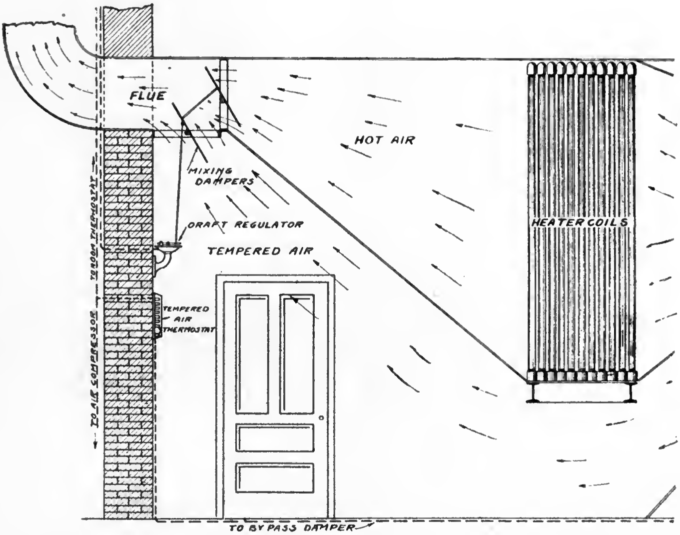


Fig. 83.

ity may be reduced as low as 30 or 35 per cent, making the air as dry as in the most arid regions. This produces a serious effect upon the inhabitants and also the furniture of the room. The decrease of humidity due to the action of the heating system occurs particularly in the indirect heating system. There has been placed on the market what is called a humid-

ostat. This is similar to a thermostat except that it is arranged so that as the moisture decreases in the room the humidostat opens up a series of steam or water jets in the air supply so that the air in passing

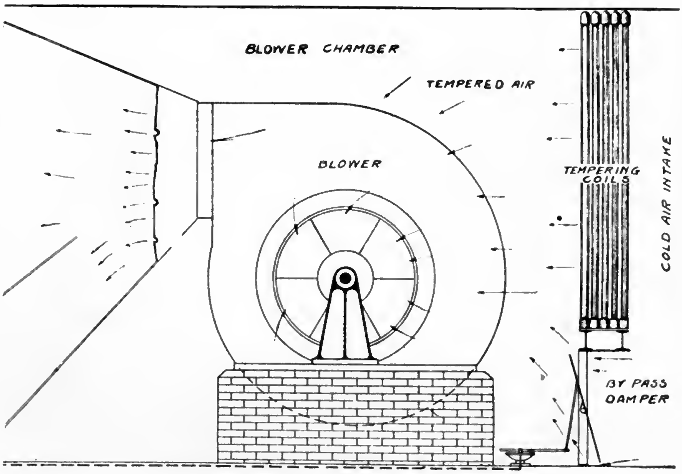


Fig. 83.

through the steam or water jet takes up moisture. When the moisture gets to a certain percentage, determined by the setting of the humidostat, the apparatus closes off automatically the steam or water jets. Such devices are particularly desirable in connection with school and hospital heating plants.

Air Washers.—In the large cities the smoke and dust in the air makes it undesirable to introduce this

air directly into the room for ventilating purposes. A great many schemes have been tried to remove the

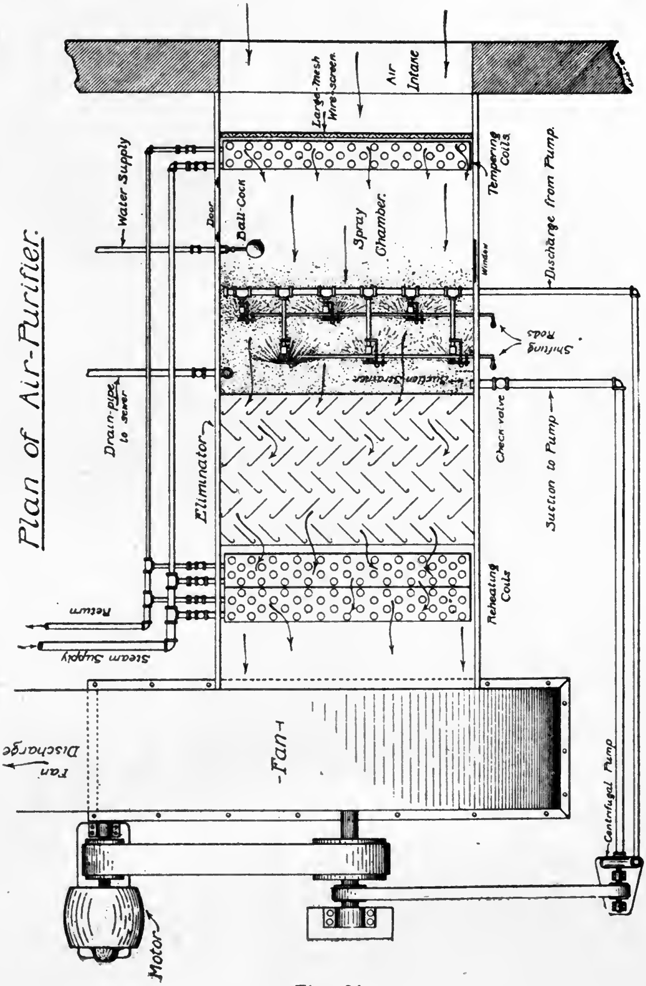


Fig. 84.

dust from the air. The earliest form was to use burlap screens through which the air passes. These screens work fairly well, but the finer dust will always be carried through them. A better plan is to pass the air through a sheet or series of sheets of water. After passing through these sheets of water the air is passed through an apparatus which removes the excess of water. Fig. 84 shows the general arrangement of an air washing system. As you will notice from the figure, the air first passes through a tempering coil which raises the temperature from 60 to 70 degrees, then passes through the sprays or sheets of water, then through the eliminator, where the excess of water is removed, and then it passes to the heating coils to be heated. The water used for washing the air is circulated over and over again by means of a small centrifugal pump driven by a motor. In some cases it is desirable that the air should be cooled. This may be done by placing cooling coils in the tank where the water collects after having washed the air, and reducing the temperature of this water to the desired point or by washing with cold water. The washing of the air with water also increases the humidity of the air. In a plant installed by the author the humidity of the air has been kept at a point not lower than 70 per cent by means of this washer. Air washing devices are very effective in removing dirt; the amount of dirt removed in some cases is very large.

Vacuum Heating Systems.

In the systems of steam heating that have been described the steam has been used at a pressure higher than that of the atmosphere. Plants are now installed

in which the pressure in the radiator may be atmospheric pressure or lower. The advantages of such a system are:

First. Where exhaust steam is used the heating will not increase the back pressure on the engines, but may reduce the back pressure.

Second. The air can be completely removed from the coils and radiators.

Third. There is perfect drainage through the returns, preventing all possibility of water hammer.

There are two distinctly different types of vacuum heating systems, one in which the air is drawn from the radiator by means of an air pump through the air valve, as shown in Fig. 75, and the other in which the radiator is fitted with a special form of return valve and vacuum is maintained on the return system by means of a pump or aspirator.

The best example of the first type is the Paul system. In this system the air valves are all connected to a system of air mains. These mains extend to an air ejector. This injector may be operated by either steam or water. The advantage of this system depends principally on the quick removal of the air from the piping and radiators. This action is often strong enough to produce a pressure in the radiator lower than atmospheric pressure.

The vacuum system of heating in which the air is drawn from the air valves is particularly desirable in hospitals and school buildings, as it does away with the objectionable odor from the air valves. This vacuum system of heating does away very largely with the attendance required by air valves.

The best example of the second type of vacuum

system is the Warren Webster. This consists of an automatic outlet valve on each coil and radiator connected to a return system in which vacuum is maintained by means of a pump. These automatic valves are traps which allow the water of condensation to pass but close as soon as the water is removed.

One of the advantages of this system is that it permits of the quantity of steam entering the radiator to be regulated without any possibility of water hammer.

This system always requires two pipe radiator connections, but has the advantage that the return piping may be made smaller than in a gravity return system.

The vacuum system has other advantages. It also permits of the radiator being placed lower than the level of the boiler and the condensation is raised from the lower level by means of the vacuum in the system. Oftentimes this enables the engineer to overcome serious difficulties in the design of the heating plant. These systems can be profitably installed in old plants where the steam mains are overtaxed, owing to frequent additions to the plant. By additions of the vacuum system these old mains can be made to carry a larger weight of steam, the vacuum system permitting a higher velocity of steam in the system without increasing the back pressure.